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WADC TECHNICAL NOTE 56-59
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**PROBE TUBE MICROPHONE FOR USE IN HIGH
TEMPERATURES AND HIGH VELOCITY AIR STREAMS**

*KENNETH W. GOFF
DERWENT M. A. MERCER
AND*

THE STAFF OF BOLT BERANEK AND NEWMAN, INC.

OCTOBER 1956

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WRIGHT AIR DEVELOPMENT CENTER

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OCTOBER 1956

AERO MEDICAL LABORATORY
CONTRACT No. AF 33(600)-23807
PROJECT No. 7211

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

F O R E W O R D

The probe microphone system described in this report was developed by the firm of Bolt Beranek and Newman Inc. under USAF Contract No. 33(600)-23807 for the Wright Air Development Center under authority of Project No. 7211, "Air Force Laboratory Energy Sources." Technical supervision of this work was the responsibility of Dr. Henning von Gierke and Dr. H. O. Parrack, Aero Medical Laboratory, Research Division, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio.

The authors would like to extend their appreciation to Dr. L. L. Beranek and Dr. Jordan J. Baruch for their early work and continued interest in the program.

A B S T R A C T

This probe microphone system was designed to fulfill the need for a microphone which could be used to make sound pressure measurements inside engine test cells and altitude wind tunnels. The sound pressure sensitive part of the microphone system (i.e., the probe tip) is capable of operating at temperatures up to 900°F, static pressures from 1.0 - 0.2 atmospheres and sound pressure levels up to 160 db re 0.0002 dyne/cm².

The probe microphone system consists of the following principal parts: (1) probe tube tips permitting a predetermined fraction of the sound pressure existing at the wall of the test cell or wind tunnel to enter the probe tube while maintaining approximate continuity of the wall surface; (2) probe tube for conducting the sound from the test cell or wind tunnel to a condenser microphone serving as the actual transducer; (3) condenser microphone for converting the sound pressure in the probe tube into an electrical signal; (4) acoustic termination for absorbing the sound wave traveling down the probe tube after it passes the condenser microphone, thus preventing reflections and standing waves.

A detailed description of the probe microphone system, complete operating instructions and performance specifications are given in the body of the report. Some notes on the theory of operation and the methods of testing the probe microphone system are given in Appendix A. Appendix B gives a review of the development program leading to the present design.

PUBLICATION REVIEW

This report has been reviewed and is approved.
FOR THE COMMANDER:


for JACK BOLLERUD

Colonel, USAF (MC)

Chief, Aero Medical Laboratory
Directorate of Research

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SECTION I

INTRODUCTION

The development and construction of this microphone was undertaken because of the need for an instrument which could be used to make measurements of the sound fields existing inside engine test cells, altitude wind tunnels, and similar structures. The microphone might thus be exposed to high gas velocities, high temperatures, high sound pressure levels and low ambient pressures. Since no known microphone and amplifier would operate at the high temperatures envisaged, it was decided to make a probe tube type of microphone to be inserted through the wall of the test structure, the end of the probe tube being in the noise field, and the rest of the microphone being outside at normal temperature and pressure.

Probe tube microphones can be divided into two general categories:

- (a) Those in which the probe tube is terminated in a cavity.
- (b) Those in which the probe tube is followed by a resistive acoustic termination.

Probe tubes of type (a) are not terminated in their characteristic impedance and generally have standing waves. The frequency response of such systems are therefore dependent upon the probe tube length and temperature because of the effect of these quantities on the resonant frequencies and also upon any variables such as static pressure

that affect the damping of the probe tube resonances. For these reasons, they would be undesirable for the applications intended for this probe microphone and a system of the second type was chosen. The probe tube termination used here is of the type described by Dr. R. W. Leonard* and is composed of a 10 ft long spiral duct following the microphone and filled with sound absorbing material in such a way as to prevent the reflection of sound and the resulting non-uniform frequency response.

* R. W. Leonard, "Resistively Terminated Probe Microphone," abstract of paper contributed to the 42nd meeting of the Acoustical Society of America, October 23-25, 1951. Journal of the Acoustical Society of America, Vol. 24, p. 113 (January, 1952).

SECTION II

DEFINITIONS

In order to avoid ambiguity throughout this report, the following definitions will be used:

(a) Condenser microphone is used to describe the actual pressure-sensitive unit (in this case an Altec Type 21 BR 150 condenser microphone) which screws into the body of the instrument.

(b) Condenser microphone system is used to describe the condenser microphone, preamplifier, power supply and associated cables.

(c) Probe microphone will be used to describe the whole instrument consisting of probe tube, termination and associated parts, together with the condenser microphone.

(d) Probe microphone system will be used to designate the probe microphone, together with preamplifier and power supply.

SECTION III

DESCRIPTION OF EQUIPMENT

A photograph of the parts of the microphone shown in "exploded" form is given in Fig. 1. The chief parts are the following:

A. Probe Tubes and Tips

The probe tube enables the probe tip to be positioned flush with the inner surface of the wall of a structure, such as a jet engine test cell, and also provides thermal isolation so that the condenser microphone remains at approximately ambient temperature. The probe tubes are made from Inconel tubing of 1/2 in. outside diameter. Four probe tubes, three 20 in. long and one 14 in. long, are provided with each microphone system.

The probe tip presents a smooth, hard surface which can be mounted flush with the surface of a wall without appreciably changing the normal wall surface. The probe tip also plays an important part in determining the sensitivity of the overall microphone system (i.e., the level of the electrical output signal for a given sound pressure level at the tip). Three different types of tips are provided on the above-mentioned probe tubes: Type F low sensitivity tips are provided on the 14-in. probe and on one of the 20-in. long probes, a Type E high sensitivity tip is provided on one 20-in. probe and a dummy solid tip is provided on the remaining 20-in. probe.

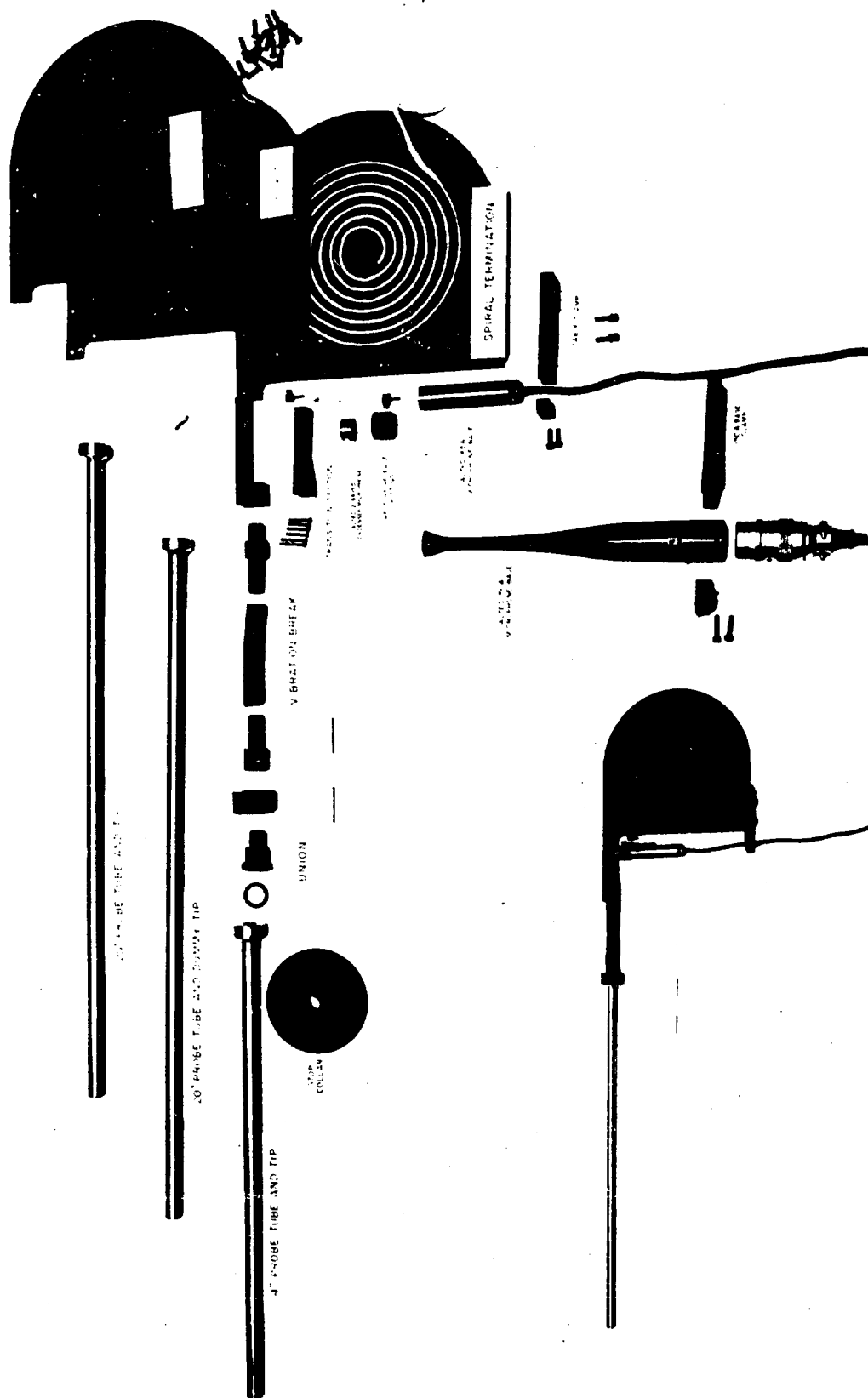


Fig. 1 - Complete Probe Tube Microphone System including alternate probe tubes, microphone bases and clamps. Assembled system shown in inset.

Each probe tube is stamped near the union fitting with a series of numbers indicating: (a) the probe microphone system with which it was supplied, (b) its approximate length in inches, and (c) the type of probe tip, i.e., E high sensitivity, F low sensitivity and D dummy. For example, probe tube 1-20-E would be the 20-in. long probe tube with a high sensitivity Type E tip supplied with system number one.

B. Union

The probe tube is attached to the remainder of the probe microphone system at this point. The union permits the probe tube to be attached to the termination unit without requiring the rotation of either member. This feature makes it possible to locate more than one probe tube and move the termination unit quickly from one to the other.

C. Vibration Break

The vibration break consists of a short length of rubber tubing with the appropriate fittings for insertion between the probe tube and the termination unit. In some instances it is helpful in reducing the level of the vibrations transmitted from the structure via the probe tube to the condenser microphone.

D. Transition Section

The transition section provides a relatively smooth transition between the circular inside cross-section of

the probe tube and the rectangular cross-section of the termination duct and also serves to hold the condenser microphone.

E. Termination

The termination consists of a rectangular duct approximately 10 ft long. The duct was formed by milling a spiral groove 3/16 in. wide and approximately 9/16 in. deep in an aluminum plate. The duct is filled with a wedge of absorbing material and is covered with a gasket and cover plate.

F. Pressure Release System

Since the microphone will be used in simulated altitude conditions and since it is undesirable that the condenser microphone be subjected to a large difference in static pressure across its diaphragm, a pressure release system is provided. This system establishes the same static pressure at the back of the condenser microphone diaphragm as exists inside the probe tube and yet insures that only a negligible amount of sound reaches the back of the diaphragm.

This system consists of (a) a unit placed between the back of the microphone and the preamplifier, (b) a connection to the center of the spiral duct via a small plastic tube and a groove in the back of the termination unit. Unit (a) also provides the necessary electrical connections between the condenser microphone and the preamplifier.

G. Condenser Microphone System

This consists of an Altec 21 BR 150 microphone, a preamplifier which attaches to the probe microphone, and a power supply which is separate and connected to the microphone by several feet of cable. Of the four probe microphone systems supplied, Systems 1 and 2 are provided with Altec M20 and Systems 3 and 4 with condenser microphone systems.

SECTION IV

PERFORMANCE SPECIFICATIONS

A. Sound Pressure Levels

The measurable range of sound pressure levels is limited at the low end by electrical noise and at the high end by the incidence of distortion. The electrical noise level for each of the four probe microphone systems is shown in Fig. 2. The electrical noise was measured in octave bands and the levels are given in Fig. 2 as equivalent sound pressure levels at the tip for the Type E high sensitivity tip. When the Type F low sensitivity tips are used, the equivalent noise sound pressure level will be increased by approximately 12 db (relative sensitivities of each of the tips are given in Figs. 6-9).

The distortion at high sound pressure levels was measured by the use of a resonant tube at a fixed frequency of about 350 cps (the experimental apparatus is described in Appendix A-6). Figure 3 gives a plot of the approximate total harmonic distortion versus sound pressure level at the tip* for both the Type E and Type F tips. This curve indicates that the probe microphone system can be used at room temperature and atmospheric pressure to a level of

* Throughout this report, sound pressure level in decibels is always used with reference to 0.0002 dyne/cm^2 .

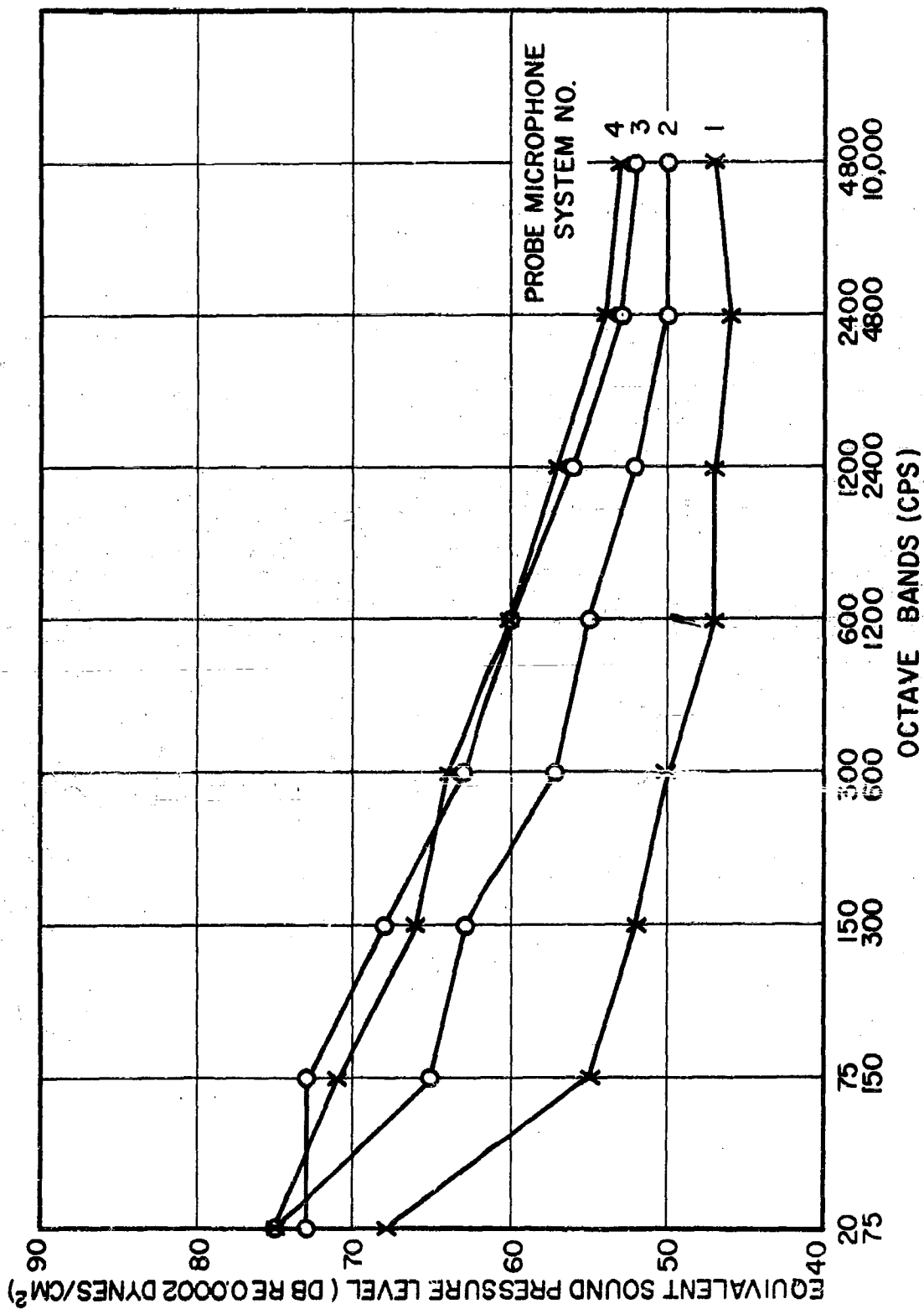


FIG. 2 NOISE LEVEL OF EACH PROBE MICROPHONE SYSTEM FOR OCTAVE BANDS. LEVELS REFERRED TO EQUIVALENT SOUND PRESSURE LEVEL AT PROBE TIP FOR TYPE E TIP.

approximately 170 db with any of the type tips supplied, without incurring more than 27 total harmonic distortion. A discussion of the distortion characteristics of the Type E and F tips is given in Appendix A-6.

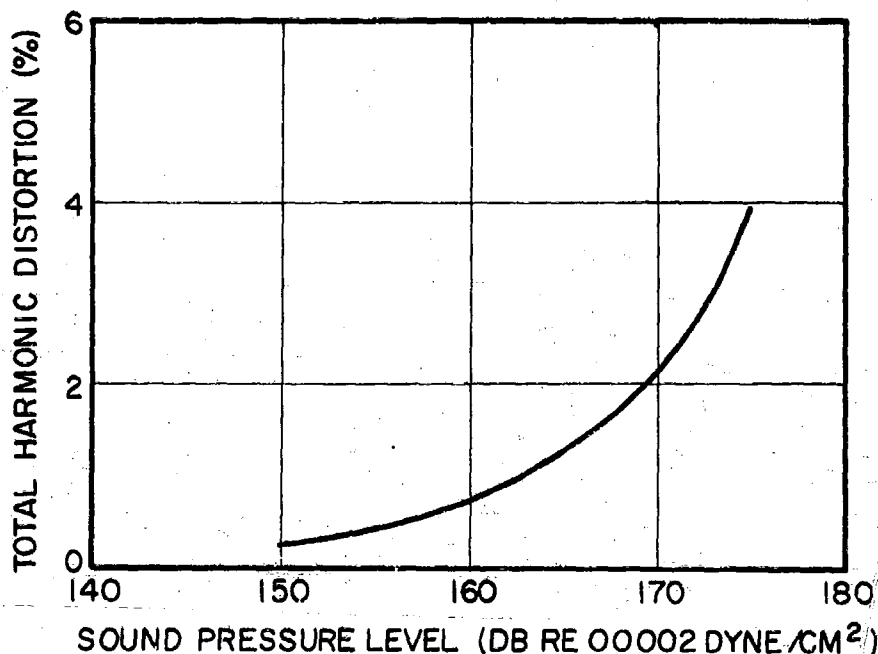


FIG. 3 PROBE MICROPHONE DISTORTION AT 350 CPS
FOR TYPE E AND TYPE F PROBE TIPS SUPPLIED

The probe tip distortion is thought to be dependent only upon particle velocity through the tip and not upon frequency. Therefore, although the data of Fig. 3 were taken for a frequency of 350 cps, the results are expected to be quite similar for all frequencies from 100 cps to

3 kcps. In the same manner, since the particle velocity within the probe tip for a given sound pressure level is to a first approximation independent of the static pressure at the tip, the distortion limits given above are expected to apply over the full range of static pressures from 1.0 to 0.2 atmospheres (see discussion of the equivalent circuit in Appendix A-1).

B. Ambient Pressure

It is necessary for the probe microphone system to be operated with the tip subjected to static pressures as low as 0.2 atmosphere while the remainder of the system, i.e., the termination and condenser microphone, is at an ambient pressure of one atmosphere. Tests were therefore made to determine (1) that the system would operate satisfactorily under these conditions, and (2) the change in sensitivity to be expected.

The method of making these measurements is described in Appendix A-2. The probe microphone system was shown to operate satisfactorily for static pressures at the tip as low as 0.2 atmosphere. The time constant for equalization of the static pressure on both sides of the condenser microphone diaphragm was less than 5 seconds.

The relative sensitivity of the probe tube microphone system versus the static pressure at the tip is shown in

Fig. 4. This sensitivity was measured at 1 kcps and is considered to be approximately independent of frequency over the range from 100 cps to 3 kcps.

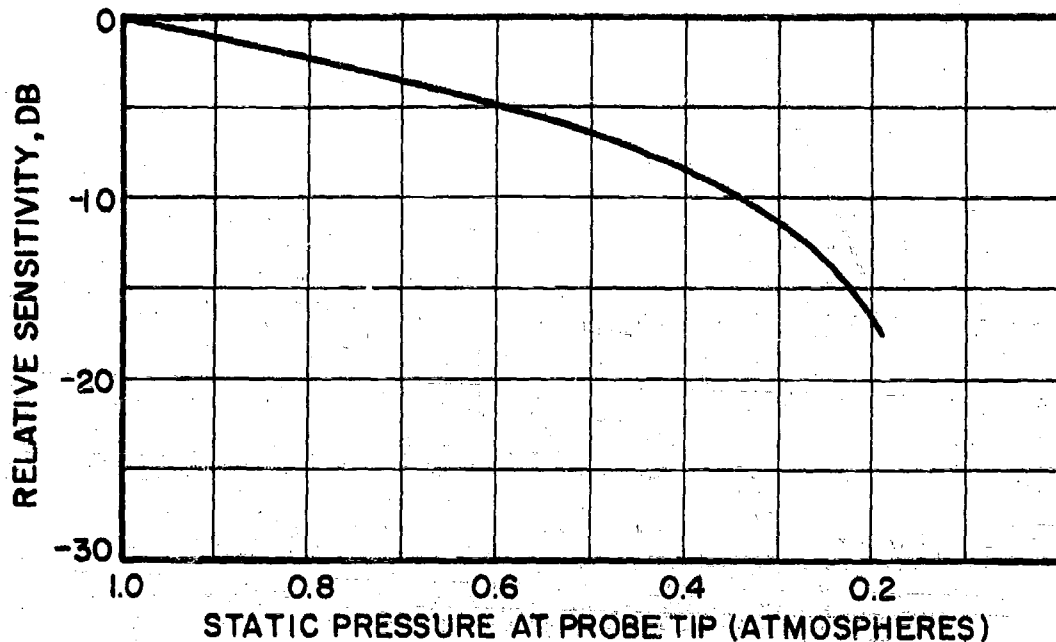


FIG. 4 RELATIVE SENSITIVITY OF PROBE MICROPHONE SYSTEM VERSUS STATIC PRESSURE AT THE PROBE TIP

C. Ambient Temperatures

The probe tube microphone system can be used to measure the sound pressures at points of temperatures as high as 900°F provided that the condenser microphone and termination unit are maintained at approximately room temperature. The effect of the temperature gradient along the probe tube was shown to have negligible effect on the frequency response of the system (see Appendix A-4).

The acoustic impedance of the probe tip changes with temperature and the resulting change in probe microphone sensitivity is given in Fig. 5. It can be seen from Fig. 5 that the temperature at the probe tip need be known only to the nearest 200°F in order to specify the sensitivity of the microphone to within 1 db.

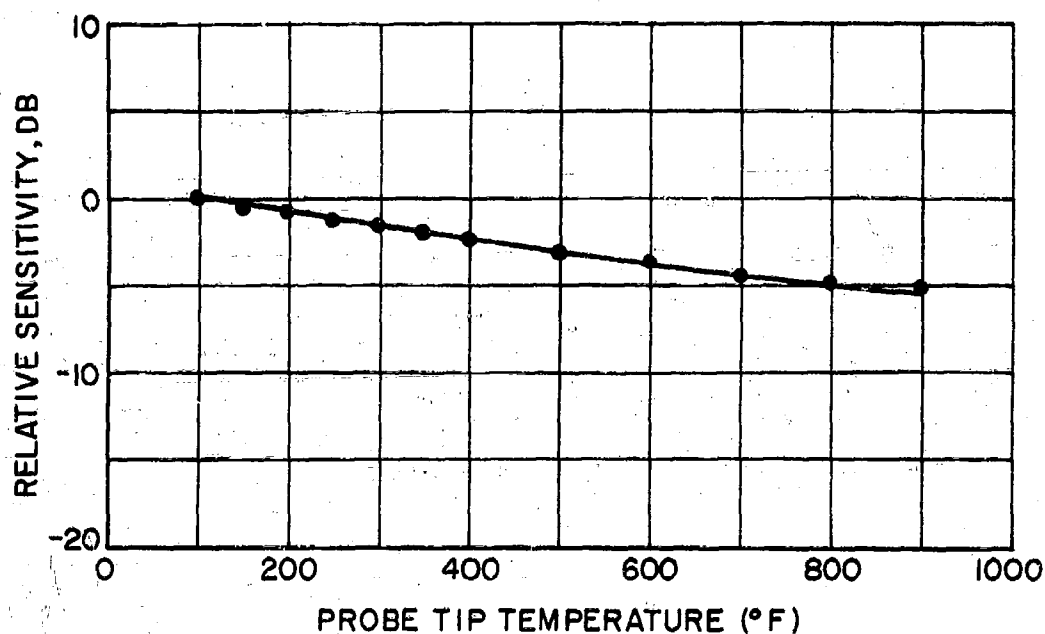


FIG. 5 RELATIVE SENSITIVITY OF PROBE MICROPHONE SYSTEM VERSUS PROBE TIP TEMPERATURE

D. Probe Tip Self-Noise

When the probe tip is mounted flush with the surface of a wall, the self-noise due to the presence of a wind stream is considered to be negligible because of the smoothness of the probe tip.

E. Frequency Response Range

Individual curves of sensitivity versus frequency are given in Figs. 6 to 9 for the four probe microphone systems with the Type E high sensitivity tips and without the pressure release units. These were measured for normal incidence by comparison with a 640 AA microphone in the EBN anechoic cube and low frequency duct.

Changing from a Type E high sensitivity probe tip to a Type F low sensitivity tip merely decreases the sensitivity of the probe microphone system by a fixed number of decibels which is independent of frequency. These correction numbers are given on Figs. 6 to 9 for all of the probe tubes and tips supplied.

The insertion of the pressure release unit between the condenser microphone and preamplifier reduces the sensitivity slightly because of the increased shunt capacity. The necessary corrections for this decrease in sensitivity are also given in Figs. 6 to 9.

It should be pointed out that there is a decrease in high frequency response of the microphone with increased length of probe tube. Figure 10 shows the attenuation of the probe tube in decibels per foot of increased length versus frequency and should be used as a correction if longer lengths of tube are employed.

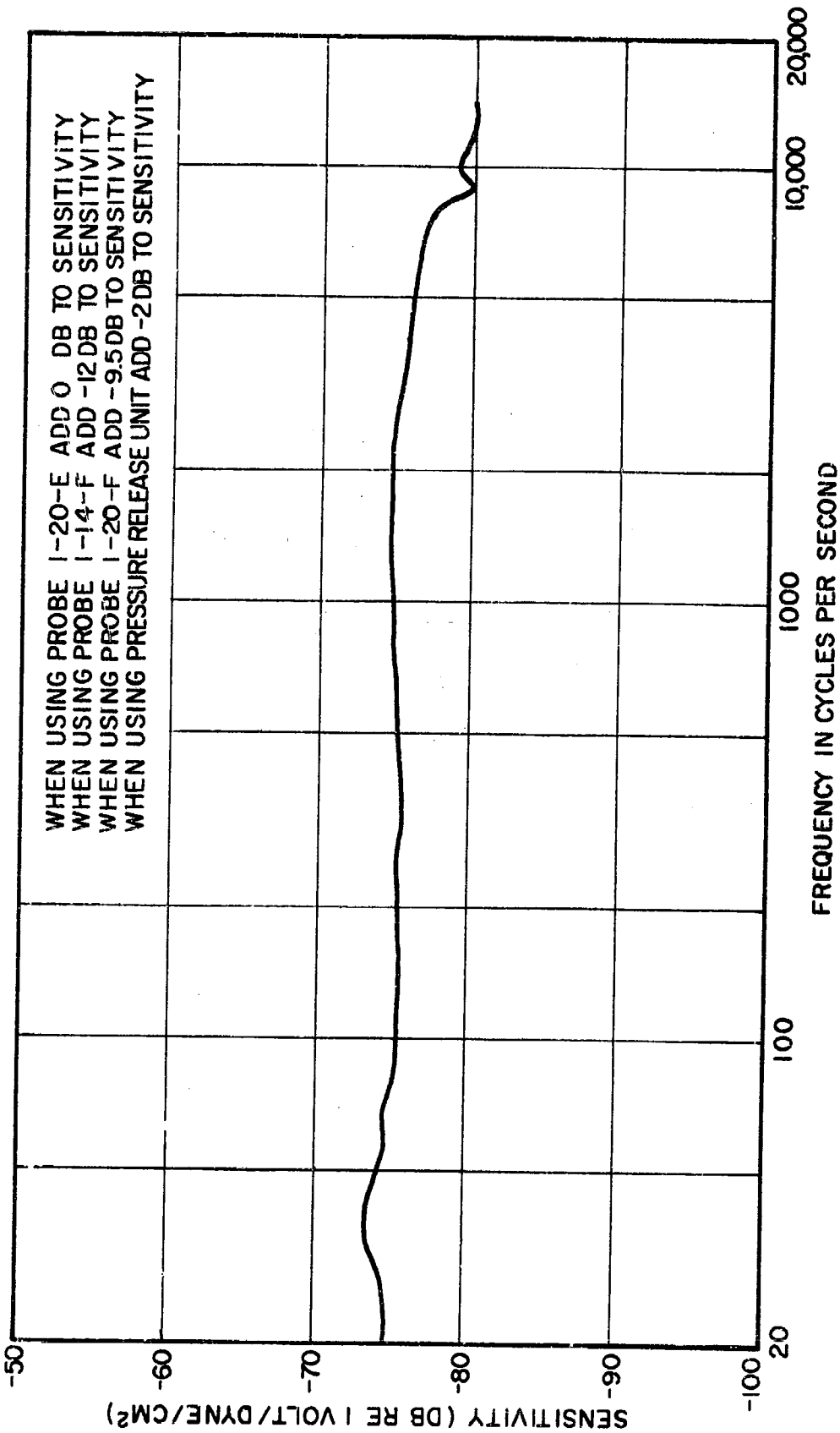


FIG. 6 NORMAL INCIDENCE RESPONSE OF PROBE MICROPHONE SYSTEM 1 AT PREAMPLIFIER OUTPUT WITH PROBE 1-20-E AND NO PRESSURE RELEASE UNIT. CORRECTIONS LISTED FOR OTHER PROBES AND PRESSURE RELEASE UNIT.

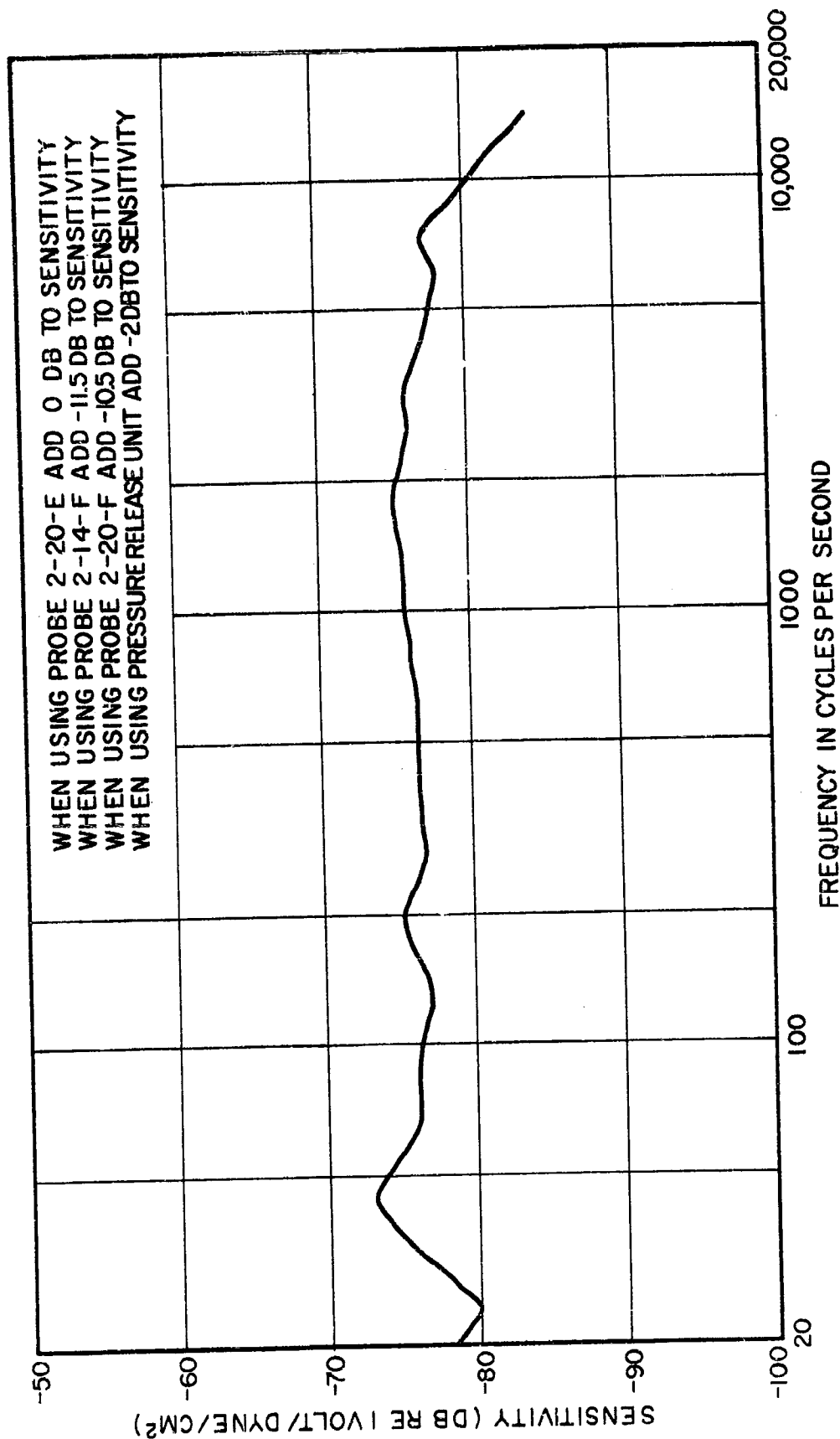


FIG. 7 NORMAL INCIDENCE RESPONSE OF PROBE MICROPHONE SYSTEM 2 AT PREAMPLIFIER OUTPUT WITH PROBE 2-20-E AND NO PRESSURE RELEASE UNIT. CORRECTIONS LISTED FOR OTHER PROBES AND PRESSURE RELEASE UNIT.

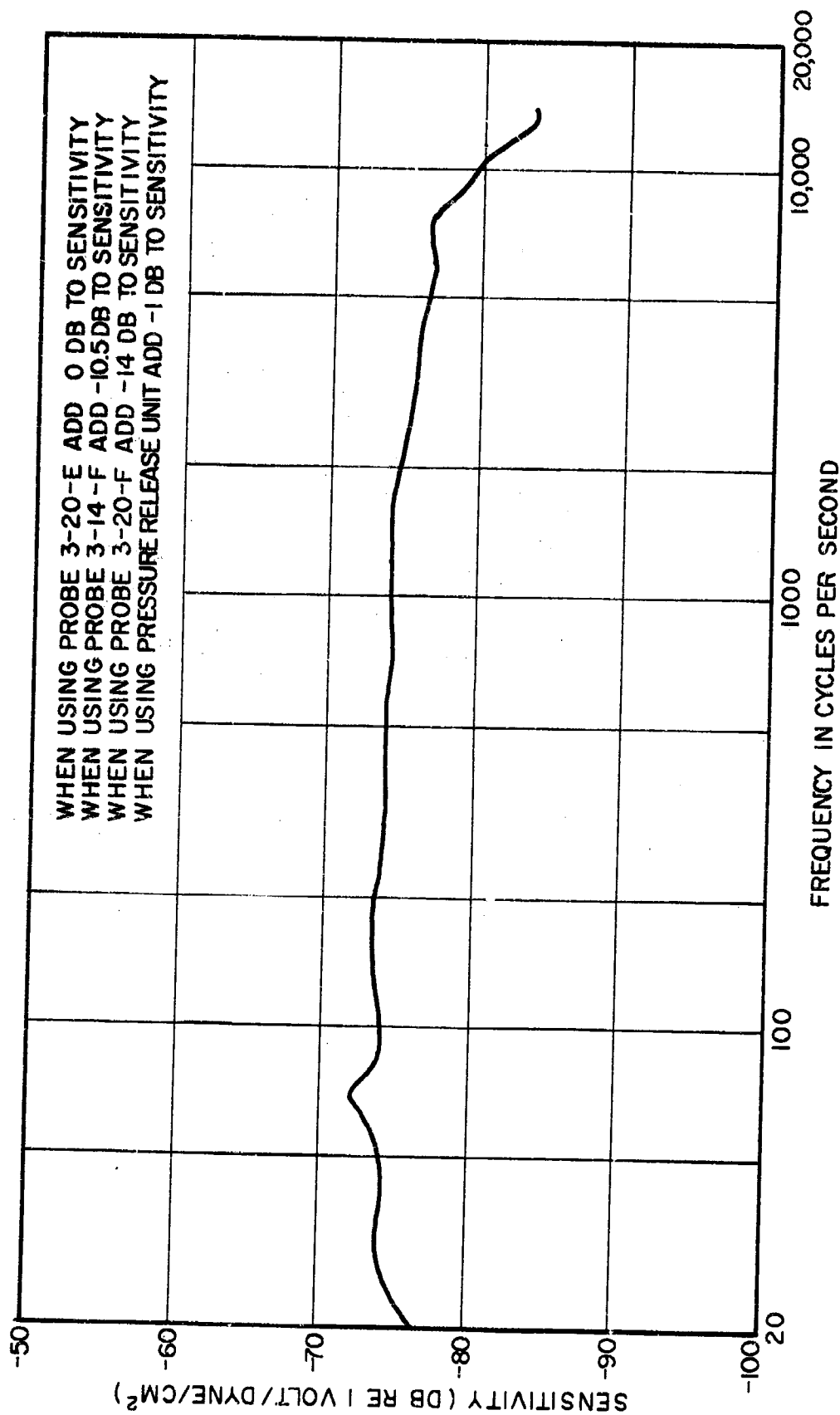


FIG. 8 NORMAL INCIDENCE RESPONSE OF PROBE MICROPHONE SYSTEM 3 AT PREAMPLIFIER OUTPUT WITH PROBE 3-20-E AND NO PRESSURE RELEASE UNIT. CORRECTIONS LISTED FOR OTHER PROBES AND PRESSURE RELEASE UNIT.

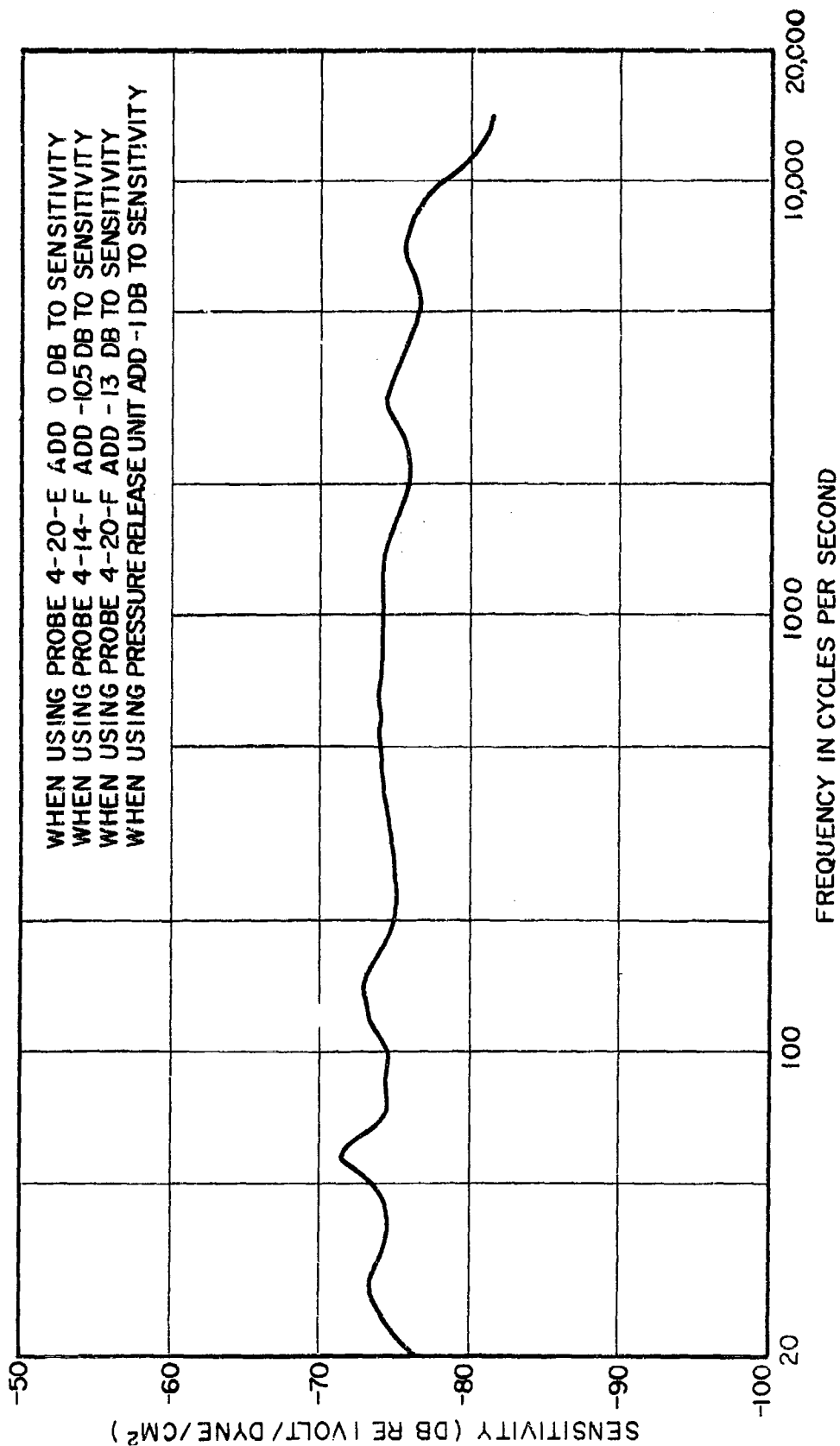


FIG. 9 NORMAL INCIDENCE RESPONSE OF PROBE MICROPHONE SYSTEM 4 AT PREAMPLIFIER OUTPUT WITH PROBE 4-20-E AND NO PRESSURE RELEASE UNIT. CORRECTIONS LISTED FOR OTHER PROBES AND PRESSURE RELEASE UNIT.

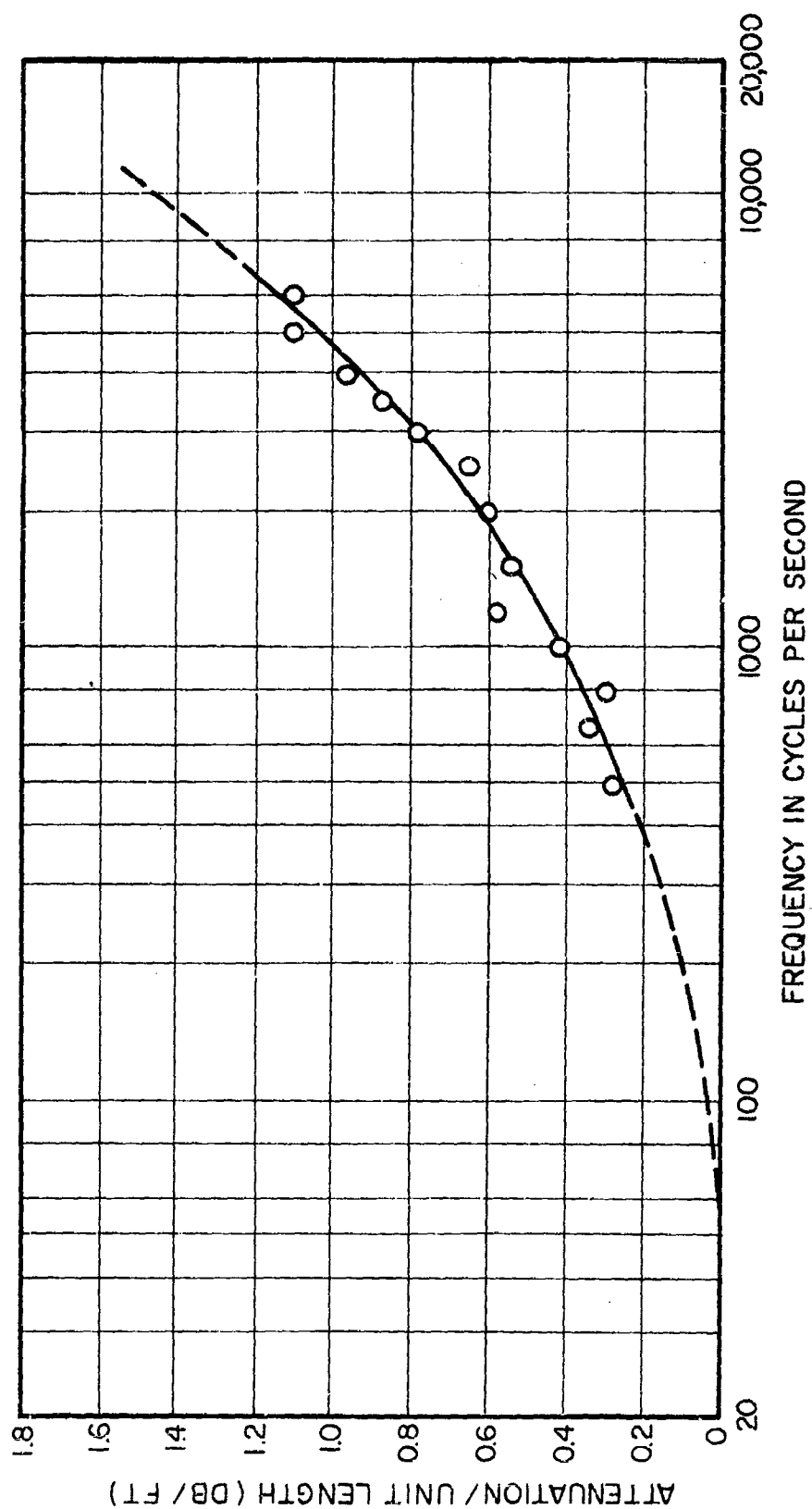


FIG. 10 ATTENUATION PER UNIT LENGTH OF PROBE TUBE VERSUS FREQUENCY.
TO BE USED AS CORRECTION WITH PROBE TUBES LONGER THAN 20 INCHES.

F. Flanking

All sound reaching the condenser microphone by paths other than through the probe tube tip constitutes a flanking signal. The sensitivity of the probe microphone system and dummy probe tube tip to an external sound field is shown in Fig. 11 with respect to the sensitivity obtained using the Type E high sensitivity tip. The measurements of Fig. 11 were made with and without the rubber vibration break after the probe microphone systems were assembled and sealed. These data may not be valid if the cover plate is removed from the termination or the transition part is removed and replaced.

G. Stability

The attenuation of the tip repeats within ± 1 db when temperature is cycled over the range from room temperature to 900°F. The overall stability of the microphone is essentially that of the Altec 21 BR 150 condenser microphone, provided that the tip is not clogged with soot or other foreign matter. The sensitivity of the Altec 21 BR 150 condenser microphone should remain constant within ± 0.5 db over a period of several months.

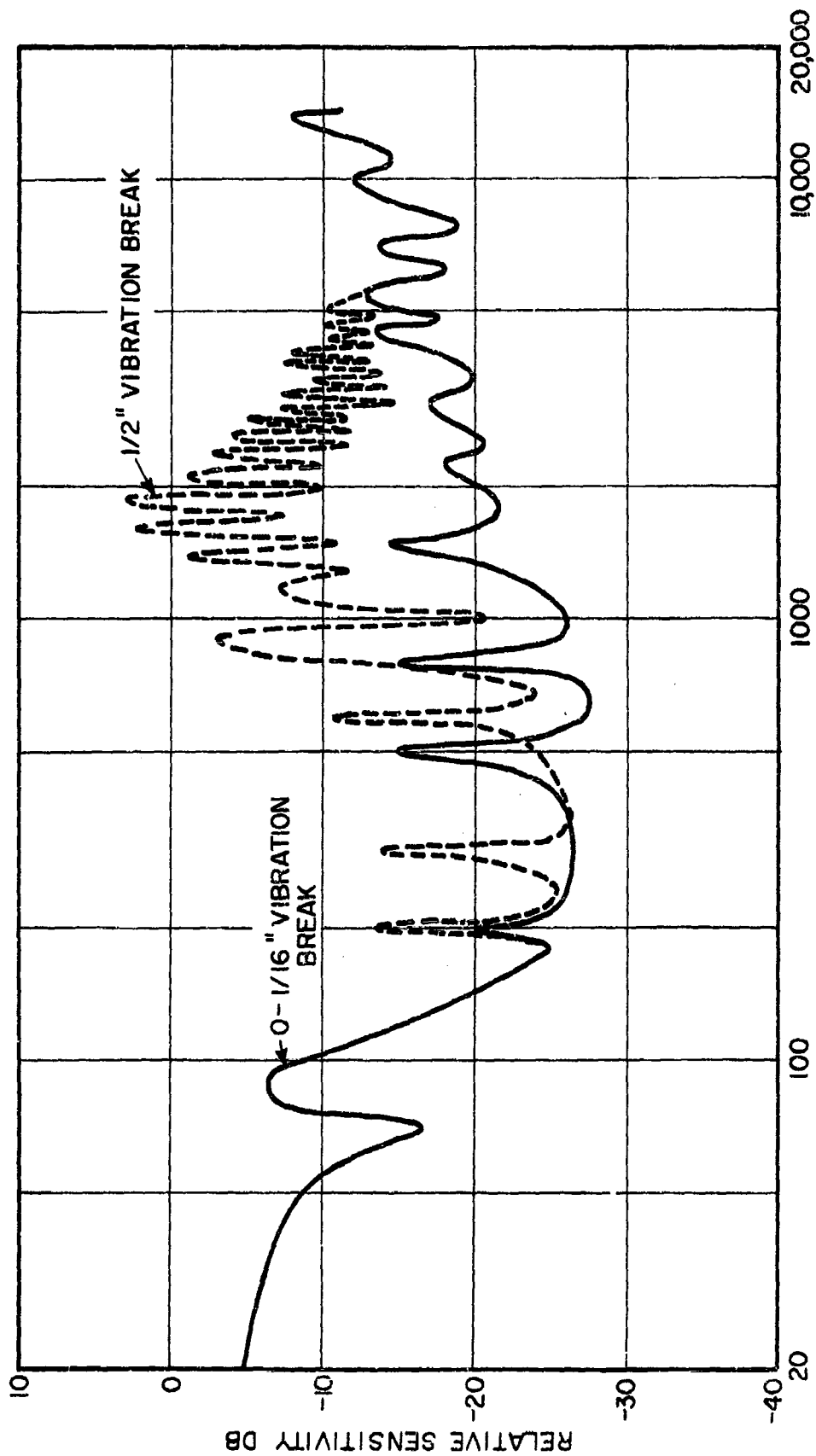


FIG. 11 SENSITIVITY OF PROBE MICROPHONE SYSTEM TO FLANKING SIGNAL.
SENSITIVITY WITH DUMMY TIP COMPARED TO SENSITIVITY WITH TYPE E TIP

SECTION V
OPERATION AND MAINTENANCE

A. Mounting

The probe tube is fitted with a stop collar so that the tube can be placed and accurately replaced through a wall such as that of a test cell so as to come just flush with the inside wall. The microphone termination unit is fitted with four holes 1/4 inch-20 so that normal tripod screws or eye bolts can be attached, enabling the microphone to be held in any position.

B. Vibration

In any situation where the probe tube itself is in contact with an intensely vibrating structure, the following procedure is recommended. The special dummy probe tube should be mounted close to the regular probe tube, connected to the termination unit and a measurement of the microphone output made. If this output is comparable with the output obtained using the regular probe tube, provision must be made to reduce the vibration of the probe tube and/or the termination unit and condenser microphone before reliable measurements can be obtained.

Experience has shown that, while the rubber vibration break supplied may reduce the vibration pick-up by the probe microphone system in some instances, it may only make the problem worse in other cases. The probable reasons for this behavior can be seen from the following examples:

(a) Vibrations normal to the axis of the probe tube - these vibrations are rather effectively isolated from the termination unit and condenser microphone by the rubber vibration break and any output signal that might be caused by the vibrations (such as from microphonics produced in the preamplifier) is reduced accordingly.

(b) Vibrations parallel to the axis of the probe tube - these vibrations are also isolated from the termination unit and condenser microphone. However, the resulting relative motion between the probe tube (essentially closed at the tip end by the high flow resistance tip) and the termination unit produces a fluctuating pressure within the probe tube. This fluctuating pressure at the condenser microphone causes an undesired output which may, in some cases, be larger than that caused by the vibrations without a vibration break in place.

From the reasoning above, it can be seen that the probe tube should be mounted in such a way as to reduce the wall to tube coupling for axial vibrations as much as possible. That is, the probe tube should be as free as possible to slide in the direction of its axis. In some cases it may be advisable to measure the vibration pick-up (using the dummy probe tip) with and without the vibration break in place in order to determine the most satisfactory arrangement.

It should also be noted that, since the Type F low sensitivity probe tips attenuate the signal approximately 12 db more than the Type E high sensitivity tips while not changing the vibration level, the Type F probe tips reduce the "signal-to-vibration" ratio accordingly.

C. Preamplifiers and Power Supplies

Of the four probe microphone systems supplied, two are provided with Altec Type 150A preamplifiers and their associated cables and Type P519A power supplies (Altec M11 systems), while the other two are provided with Altec Type 165A preamplifiers and their associated cable and Type P525A power supplies (Altec M20 systems). In both cases, the power supplies are for rack mounting. Grid resistors (22 megohm) have been added to the Type 150A preamplifiers in order to permit stable operation with relatively leaky microphones.

The two types of power supplies have been modified slightly, as indicated in the schematics, so that they both provide direct output connection (via coupling capacitors) from the preamplifier cathode followers to the external load. The output impedance is approximately 3000 ohms and the overload point occurs for an output of either approximately 30 volts rms or 0.5 milliamperes, whichever occurs first. Thus, they can deliver approximately 30 volts rms into loads of 60,000 ohms or higher and for lower impedances the maximum output voltage must be reduced proportionately.

D. Care of Tip

The probe tip should not be subjected to temperatures above 950°F for prolonged periods*. If the tip should become covered in soot or otherwise clogged, the cleaning procedure specified by the manufacturer of the sintered material is to immerse the tip in a boiling solution of six parts of water and one part of commercial nitric acid for ten minutes. This should be followed by a thorough washing in demineralized or distilled water.

The attenuation of the probe tip increases greatly when the tip becomes wet and therefore care must be taken to insure that the tip is dry during use. The probe tip may be dried quickly by applying external heat. However, in drying the probe tip the following precautions should be observed: (a) the union fitting of the opposite end of the probe tube should not be allowed to become hot enough to damage the neoprene sealing compound; (b) the probe tip should not be placed directly in a flame in such a way as to deposit soot or other combustion products on it.

* The following information regarding the high temperature limitation of the probe tip was supplied by the manufacturer, Micro Metallic Corporation:
"A normal temperature limitation of 950°F is set for extended periods of operation ranging from several months to several years depending upon the corrosive nature of the gases. For short periods of operation, higher temperatures of operation would be permissible but our experience in this area is extremely limited. Some of our porous media have been exposed to temperatures up to 1800°F for several hours without apparent adverse effects both flow-wise and strengthwise, but such usage is strongly discouraged."

E. Gaskets and Connections

The cover plate for the termination is sealed with a gasket and with gasket cement, while the transition piece is sealed with gasket cement only. It is strongly recommended that these parts should not be removed unless absolutely essential, since they have been carefully fitted and tested for leaks. If they must be removed, they should be resealed and again tested.

The condenser microphone, pressure release connection and vibration break are, however, made for occasional removal and replacement, and the threads are simply sealed with vaseline.

F. Care of Condenser Microphone

The condenser microphone should be protected from high humidity and mechanical shock. If the probe microphone system is not to be used for a prolonged period of time, the condenser microphone should be detached and stored in a desiccator.

APPENDIX A

A-1. Equivalent Circuit for Probe Tube Microphone

An electrical analog of the probe tube microphone acoustic system provides a useful basis for explaining the change in sensitivity of the system with tip temperature and static pressure. The equivalent circuit is also useful in explaining the frequency response throughout the mid-frequency and very low frequency regions and in providing a basis for predicting the frequency dependence of the probe tip distortion.

An approximate equivalent circuit for the probe microphone is given in Fig. A-1. Pressure is analogous to voltage and particle velocity is analogous to current. The external sound field is represented by the blocked pressure P_B and radiation impedance Z_A as seen by the probe tip. The probe tip is represented by a pure flow resistance R . The probe tube and spiral termination are represented by lossless and lossy transmission lines respectively. (The probe tube is assumed to be short enough to have negligible attenuation. See Fig. 10.) The microphone is located in the transition region between probe tube and spiral groove and the back of the diaphragm is connected to the center of the spiral via the pressure release system. Therefore, it is actuated by the difference in pressure between the two ends of the spiral termination.

Figure A-2 shows the simplified equivalent circuits for the mid-frequency range (approximately 100-3000 cps)

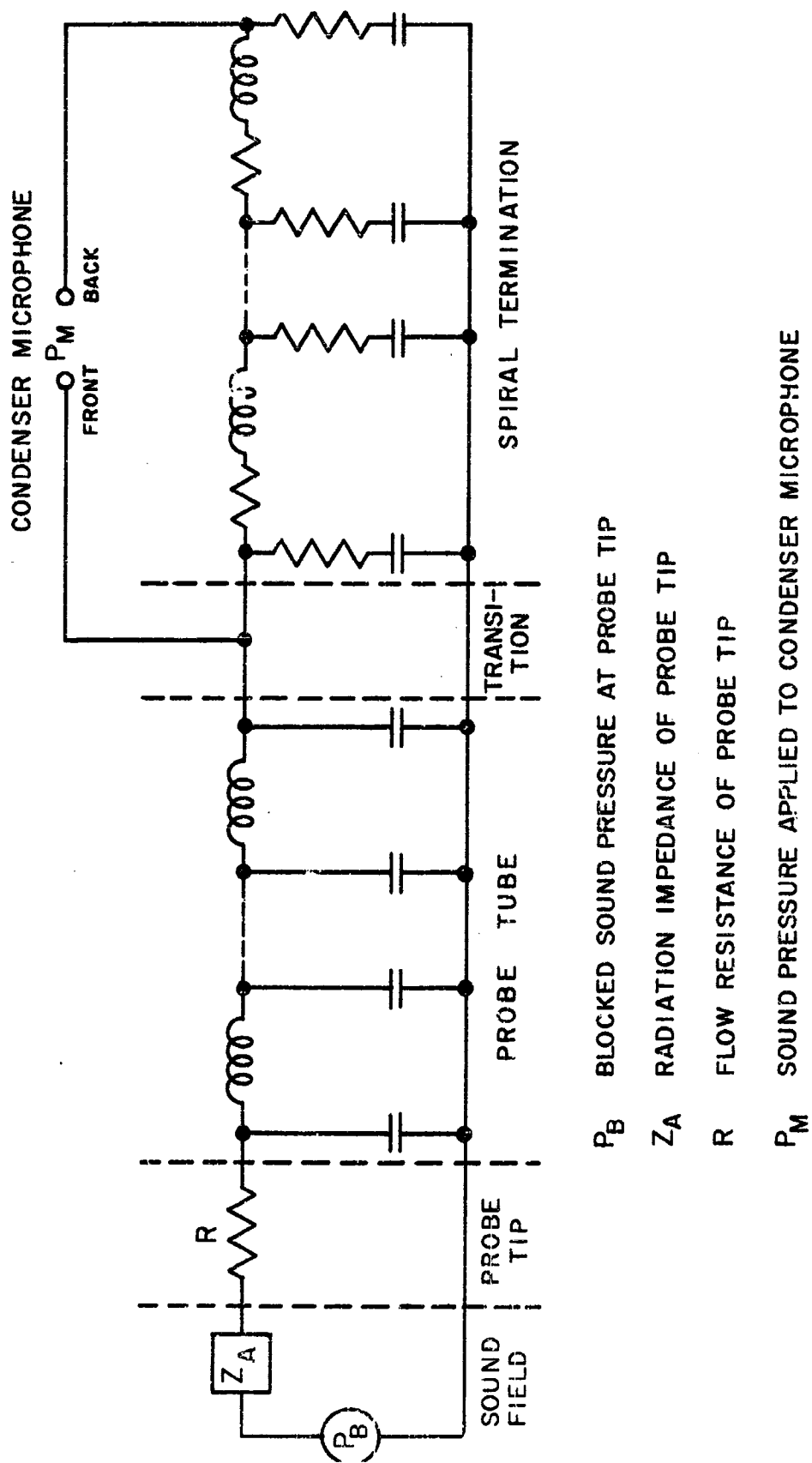
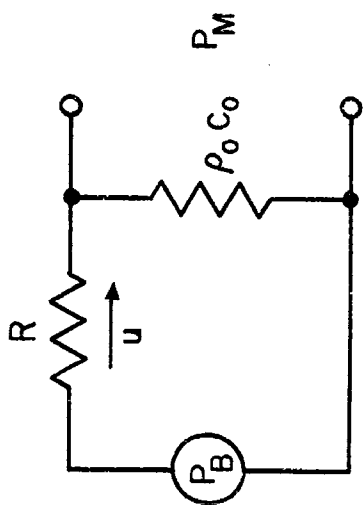
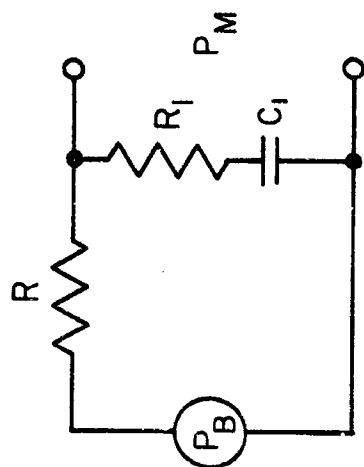


FIG. A.1 APPROXIMATE EQUIVALENT CIRCUIT FOR PROBE TUBE MICROPHONE SYSTEM



MID-FREQUENCY



VERY LOW FREQUENCY

$$\frac{P_M}{P_B} = \frac{1}{1 + \frac{R}{\rho_0 c_0}}$$

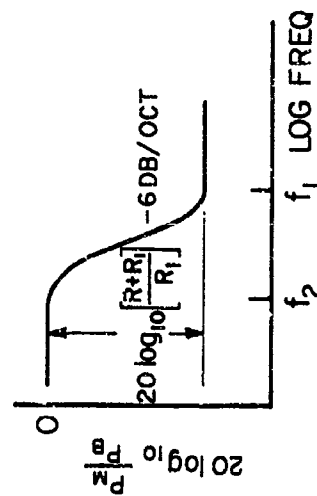


FIG. A.2 SIMPLIFIED EQUIVALENT CIRCUITS FOR PROBE TUBE MICROPHONE SYSTEM

and the very low-frequency range (approximately 2-20 cps). For the mid-frequency range probe tube attenuation and cross modes are negligible and the termination is assumed to provide perfect absorption of the sound wave so that the probe tube is effectively terminated in its characteristic impedance $\rho_o c_o$ where ρ_o is the density of air and c_o is the speed of sound. For the 3/8 in. diameter probe tube and frequencies up to 3 kcps, Z_A can be shown to be very small compared to R and the ratio of microphone pressure P_M to pressure at the probe tip P_B becomes approximately

$$\frac{P_M}{P_B} \approx \frac{1}{1 + \frac{R}{\rho_o c_o}} \quad (1)$$

Note that so long as the conditions assumed for the mid-frequency analog circuit are fulfilled, the probe microphone system has the same frequency response as the condenser microphone used to detect P_M and a sensitivity decreased by the factor $[\frac{1}{1 + R/\rho_o c_o}]$.

It is also of interest to consider the particle velocity in the probe tip. With reference to the mid-frequency equivalent circuit of Fig. A-2, the particle velocity u is given by:

$$u = \frac{P_B}{R + \rho_o c_o} \quad (2)$$

Since R is much larger than $\rho_o c_o$ (for Type E tips $R \cong 4 \rho_o c_o$ and for Type F tips $R \cong 14 \rho_o c_o$) equation (2) indicates that the particle velocity in the probe tip for a given sound pressure is very nearly independent of $\rho_o c_o$ and therefore very nearly independent of the static pressure. For example, the change in $\rho_o c_o$ of 5:1 resulting from decreasing the static pressure from one atmosphere to 0.2 atmosphere only increases the particle velocity by 1.5 db for the Type E tip and 0.5 db for the Type F tip. Equation (2) also indicates that the particle velocity in the tip is independent of frequency.

It is thought that the flow resistance for a given type of porous material becomes non-linear when some maximum allowable particle velocity is exceeded. The above discussion would therefore indicate that the maximum sound pressure level for a given probe tip is approximately independent of frequency and static pressure. Thus, the 2 per cent distortion points determined for the probe tips at atmospheric pressure and 350 cps should apply approximately over the ranges of 1.0-0.2 atmospheres and 100-3000 cps.

As the frequency decreases below 100 cps the anechoic termination provided by the absorbing material in the spiral groove becomes less effective, and finally a frequency region is reached in which damped standing waves are produced in the probe tube with the associated variations in sensitivity. This region can be seen to extend from approximately 100 cps to 20 cps in the low frequency response curve of Fig. A-3.

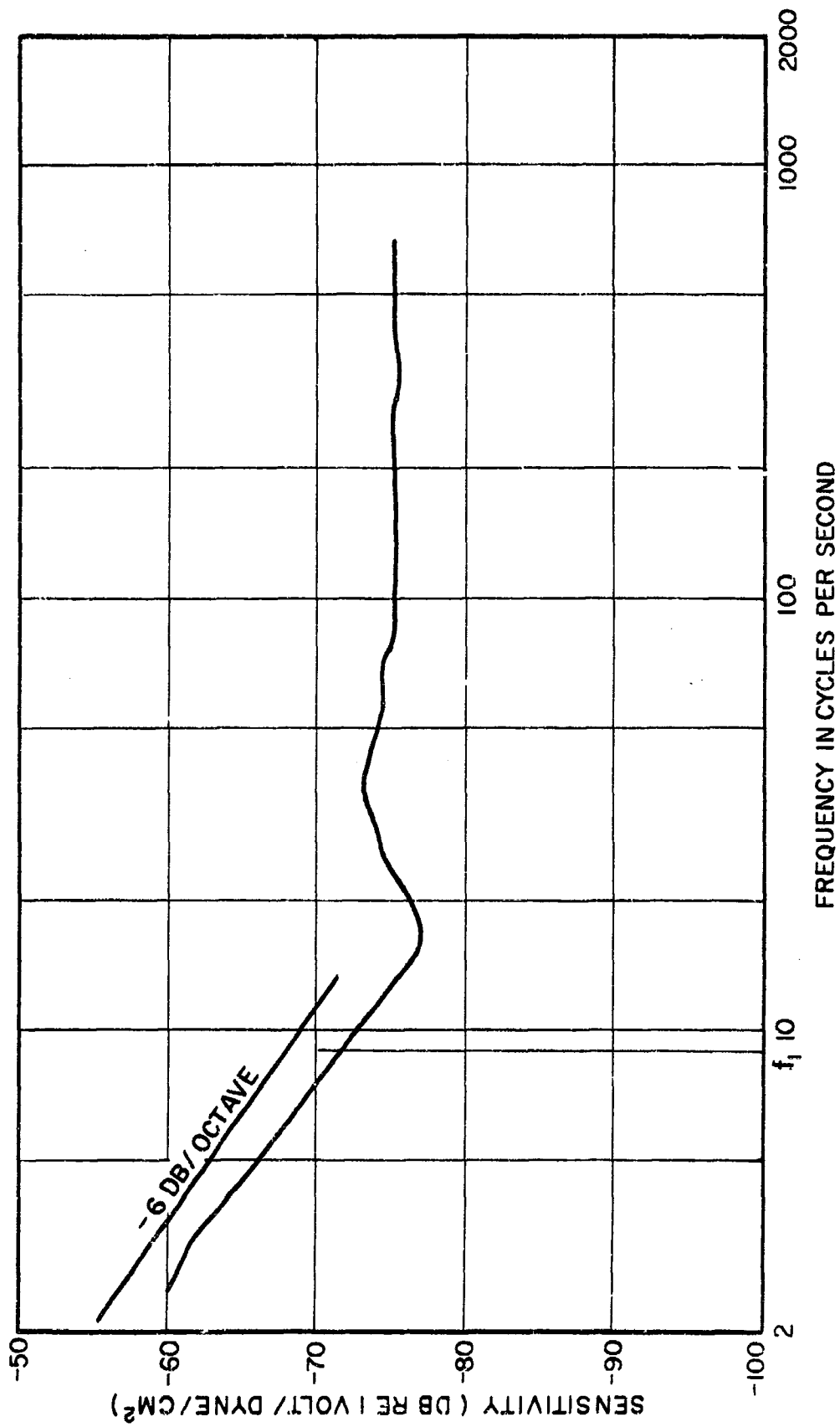


FIG. A.3 LOW FREQUENCY RESPONSE OF PROBE MICROPHONE SYSTEM I WITH PROBE TUBE I-20-E

The probe microphone sensitivity is strongly dependent upon the damping characteristics of the termination and therefore, the largest spread in frequency response characteristics occurs in this region.

Below this region (i.e., below approximately 20 cycles) the system can again be represented by an approximate equivalent circuit of the form shown in Fig. A-2. The spiral groove is now represented by a compliance and series resistance R_1 and C_1 . For frequencies lower than f_2 the tip flow resistance R is not effective in producing an attenuation. In other words, for very low frequencies the pressure inside the tube must equal the pressure outside the tip since it is a closed system.

Since the slope of the microphone response between f_1 and f_2 is 6 db per octave, this region can be rendered uniform in response by a simple 6 db per octave roll-off network inserted in the electrical system following the microphone preamplifier and rolling off below f_1 cps. Figure A-3 shows the unequalized response on probe microphone system 1 in this region. By the use of an equalizing network, a large part of the region from f_2 to f_1 could be utilized. The probe tube tip is giving less and less attenuation as the frequency decreases from f_1 to f_2 , hence for very high sound pressure levels at the tip, the condenser microphone in the probe tube microphone system may overload before the probe tip overloads. The 2 per cent distortion point measured at 350 cps will therefore not apply in this region from f_1 to f_2 .

A-2. Low Ambient Pressure Measurement

The apparatus for this is shown diagrammatically in Fig. A-4. A small loudspeaker unit is used as a source, and a WE 640 AA microphone is used as a monitor. The frequencies employed, 700 and 1000 cps, are so low that any cross modes in the cavity are considered to be unimportant, and the pressures at the two microphones are assumed to be the same. The apparatus was exhausted by a commercial compressor, the tubing being connected to its inlet. The pressure was measured by a commercial dial vacuum gauge.

In operation the pressure was set at a fixed value and measurements of the outputs of the two microphones were made at 700 and 1000 cps. (These frequencies were to some extent dictated by the characteristics of the source and by vibration picked up by the probe microphone.) The relative output of the probe microphone was corrected by the known variation in sensitivity with ambient pressure of the 640AA microphone. A set of readings was also taken with an open probe tube; this gave, again using the 640AA microphone as a reference, the change in sensitivity of the Altec condenser microphone with change in ambient pressure.

Referring to Fig. A-2 showing the mid-frequency equivalent circuit, the change in $p_o c_o$ will be directly proportional to the pressure since the speed of sound is independent of pressure. If it is assumed that the flow resistance R of the tip is independent of pressure, then

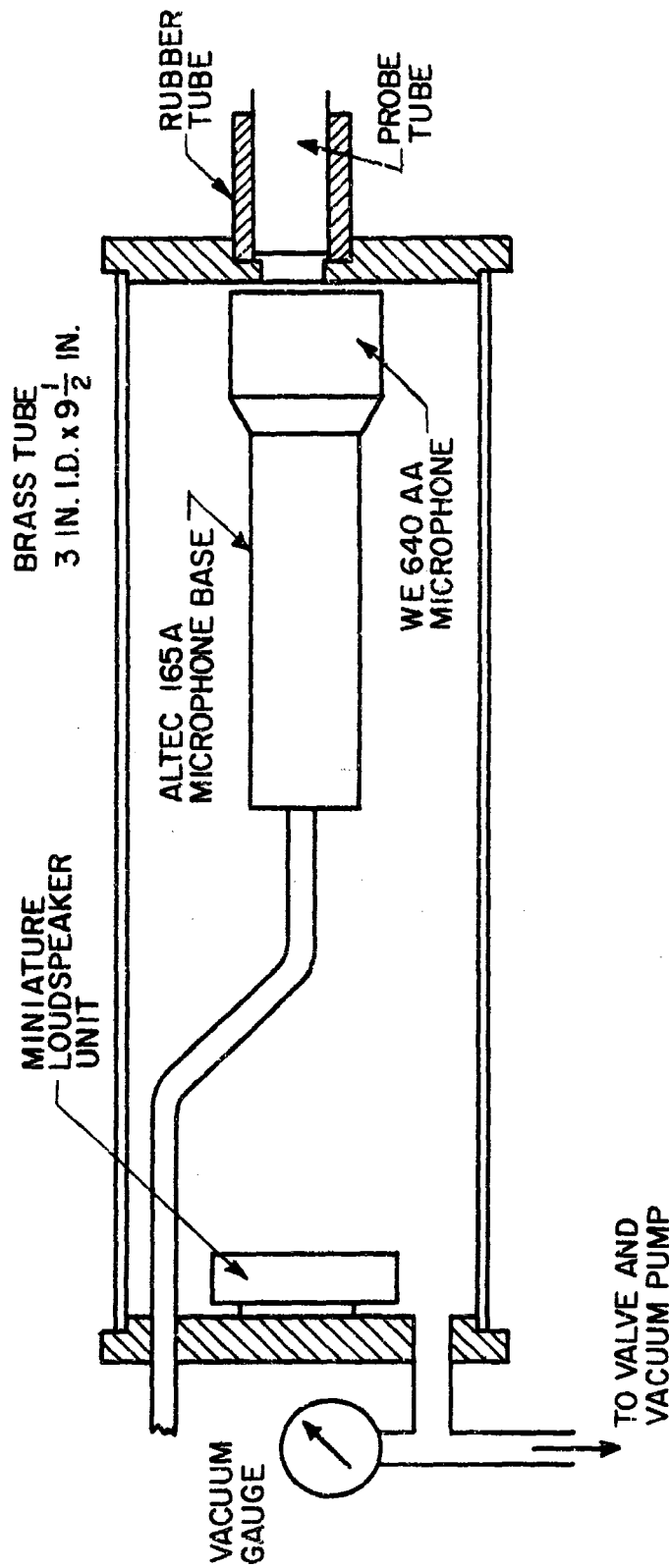


FIG. A4 APPARATUS FOR COMPARATIVE SENSITIVITY MEASUREMENTS AT LOW AMBIENT PRESSURES

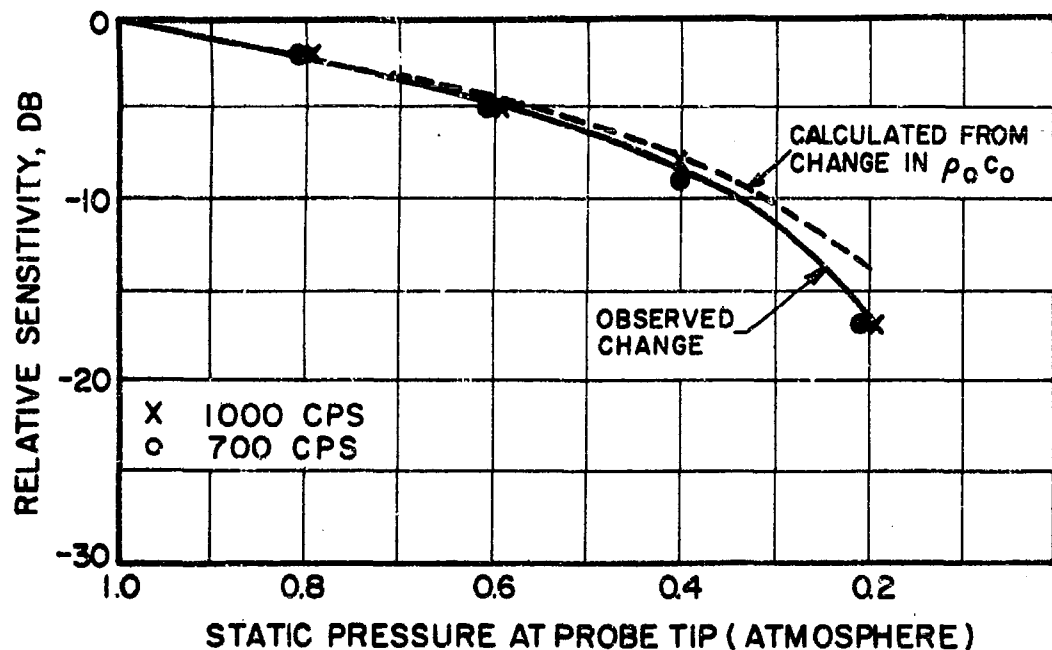


FIG. A.5 CHANGE IN PROBE MICROPHONE SENSITIVITY WITH CHANGE IN STATIC PRESSURE

the change in pressure at the condenser microphone due to this variation in R is shown as the dashed curve of Fig. A-5. The full line is drawn through the observed points, and the comparison indicates that this effect is the major cause of the overall change in sensitivity.

A-3. High Temperature Flow Resistance

The apparatus used for this determination is shown in Fig. A-6. It will be seen that the tip is surrounded on both sides by copper scrubble; the reason for this is that the air passing through the tip, and the air on

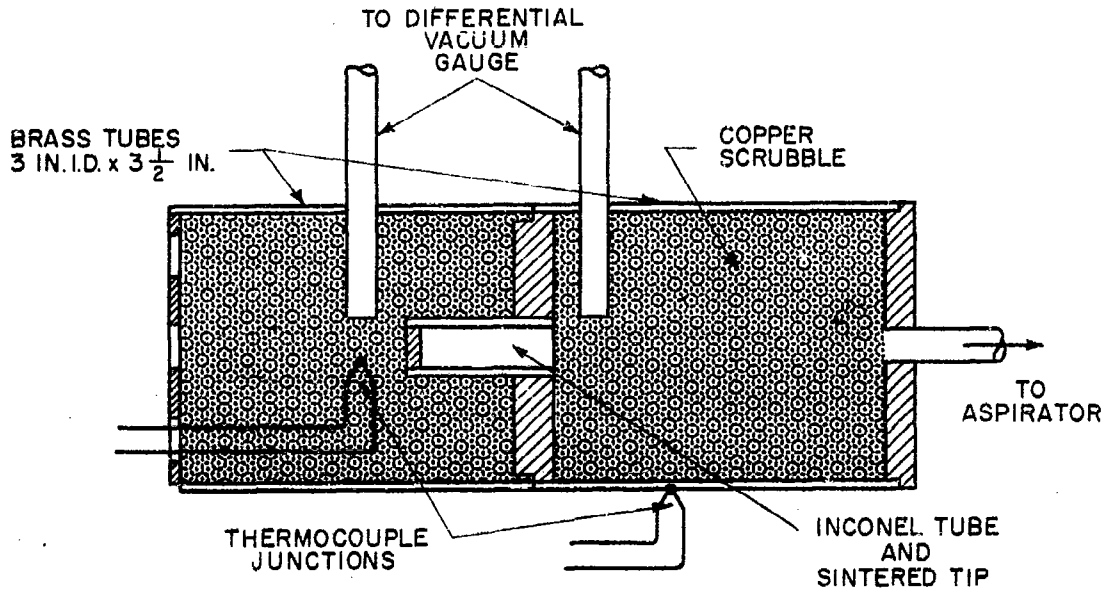


FIG. A6 APPARATUS FOR FLOW RESISTANCE MEASUREMENTS AT HIGH TEMPERATURES

either side, must all be at the same temperature. This whole apparatus, which was made of brass and copper, was heated with several blow torches until uniformity of temperature, as evidenced by the two thermocouples, was obtained. As the amount of air drawn through in any one

measurement is about one-quarter of the capacity of the whole apparatus, it was considered that no serious change in temperature of the air would take place.

A further important point is that when using this apparatus the change in volume of air due to the change in temperature must be accounted for, since the air is actually measured in the flow resistance apparatus at room temperature.

In Fig. A-7 flow resistance is plotted as a function of temperature for pressures of 2.5 and 10 in. of water; reasonable agreement between the measured points and the theoretical $R = R_0 \left(\frac{T}{T_0} \right)^{0.7}$ law will be observed. Figure A-8 shows the linearity obtained at each temperature; it will be seen that linearity does not change significantly, and hence distortion should not be greatly increased at higher temperatures.

A-4. Thermal Gradient in Probe Tube

In order to investigate the effect of different temperature gradients along the probe tube on the sensitivity of the probe tube microphone system for a given tip temperature, the following data were taken. These data were taken on a 1/2 in. inside diameter probe tube and should apply equally well to the 3/8 in. inside diameter tube used in this probe tube microphone system.

A heating coil and thermocouple were located at the tip of the probe tube and the temperature at this point was

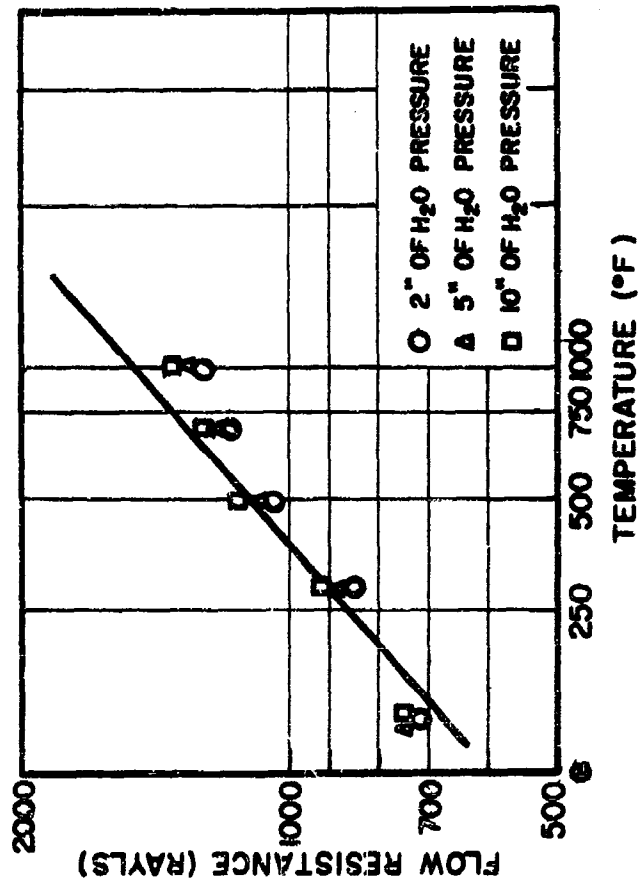


FIGURE A.7

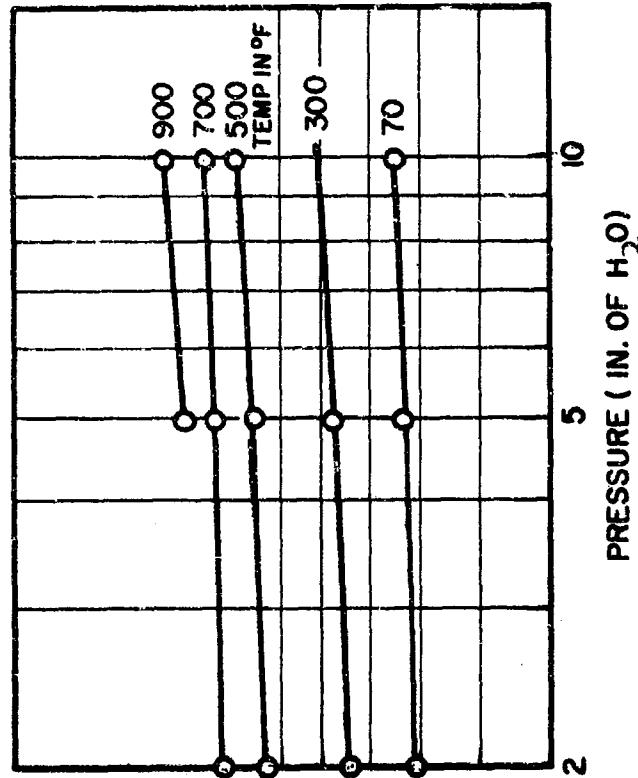


FIGURE A.8

FLOW RESISTANCE OF TYPE F 1/8" THICK PROBE TIP VERSUS TEMPERATURE AND PRESSURE

maintained at 900°F. The temperature gradient was controlled by the geometry of the heating coil and the addition of asbestos insulation and water saturated wicks for each of the gradients shown in the inset of Fig. A-9. The frequency response of the probe tube microphone system was measured using 1/3 octave bands of noise and the BBN low frequency duct. These data are shown in Fig. A-9 with the zero reference taken as the sensitivity of the system at room temperature. These data indicate that within the tolerances of this instrument the frequency response is independent of gradient along the probe tube.

A-5. Effect of Probe Tip Temperature on Sensitivity

To determine the absolute dependence of the sensitivity upon the temperature, the following test was made. The tip was heated to about 900°F, placed in the BBN microphone calibration duct within about an inch of a 21 BR 180 monitor microphone, a 100 cps signal applied to the duct loudspeaker and a level recording taken as the tip cooled with the temperatures marked. It was noted that as the tip was moved about over a range of a few inches there was no significant change in output, indicating that there were no appreciable standing waves. A plot of relative probe microphone system sensitivity with respect to its room temperature value versus tip temperature is given in Fig. 5 with the measured points shown.

There are three factors which, either separately or together, could cause a change in sensitivity when the tip is heated. Referring to the equivalent circuit diagram in Fig. A-1, there could be a change in radiation impedance, a

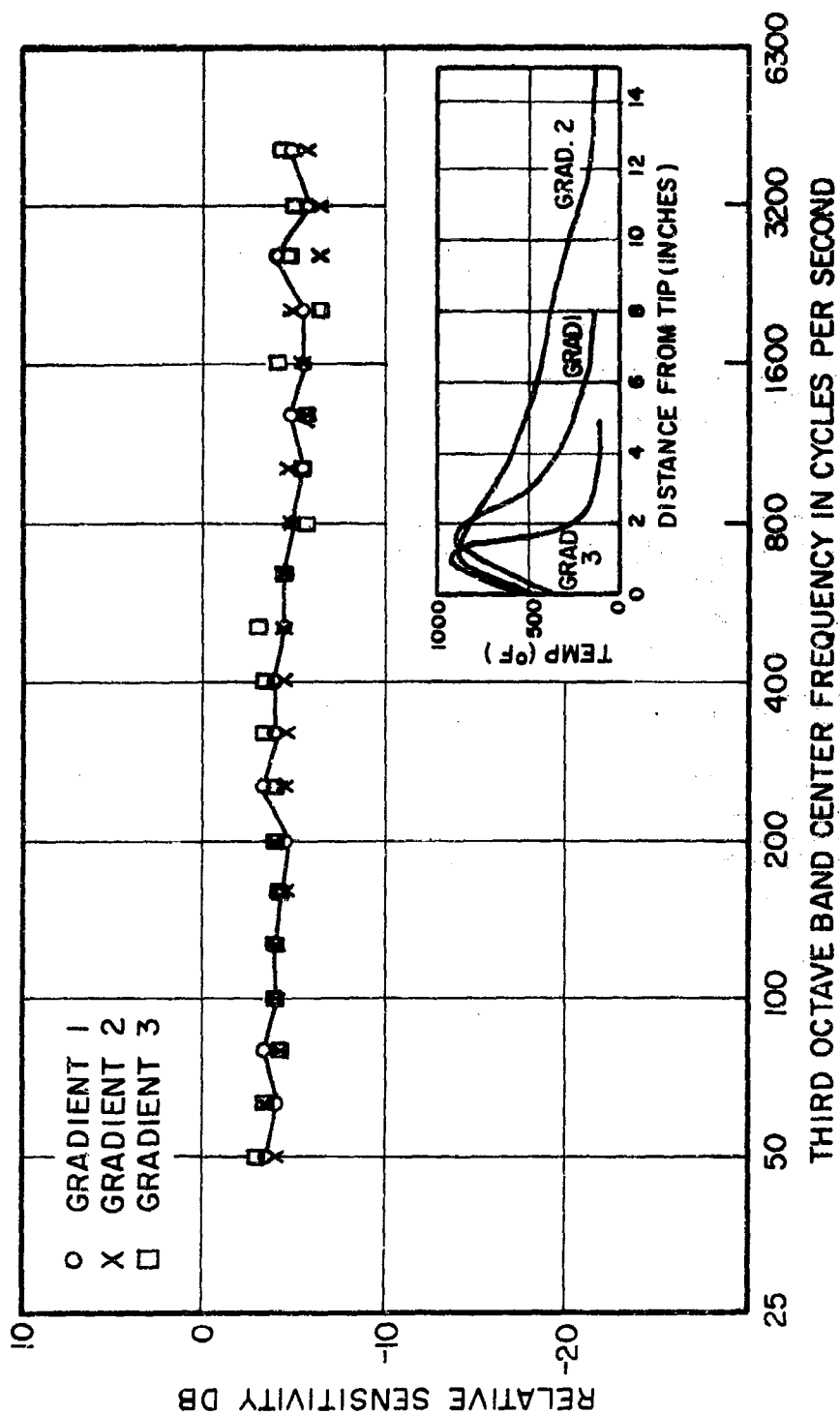


FIG. A.9 RELATIVE SENSITIVITY OF PROBE TUBE MICROPHONE VERSUS FREQUENCY FOR THREE TEMPERATURE GRADIENTS ALONG PROBE TUBE (1/2" I.D. x 30" INCOLOY TUBE)

change in tip flow resistance, or a change in impedance looking down the tube, which is normally $\rho_0 c_0$.

The dc flow resistance of the material was measured at several temperatures, and a graph is shown in Fig. A-7. These data agree quite well with the theoretical relationship $R(T) = R(T_0) (T/T_0)^{0.7}$ predicted by considering the flow resistance as proportional to the viscosity of the gas. If the effects of this change in flow resistance only are taken into account in computing the sensitivity of the microphone the solid line in Fig. 5 is obtained. By comparison of the measured points with the computed curve, it can be seen that the change in tip flow resistance accounts for essentially all of the measured change in sensitivity, and it is therefore considered that the other effects are unimportant.

A-6. Distortion Measurements

In order to obtain the quantitative information necessary for rank ordering the several tip materials considered for use in the probe microphone system the following resonant tube system was constructed. With reference to the sketch, Fig. A-10, the resonant tube system consists of (1) plywood enclosure for the 8 in. loudspeaker, (2) 8 in. long, 5/8 in. inside diameter steel tube connecting the loudspeaker to the measuring cavity and providing a quarter wave resonant matching network to match the high impedance of the test cavity to the relatively low impedance of the loudspeaker, (3) test cavity consisting of a 3 in. ID x 1/16 in. long tube with provision for mounting

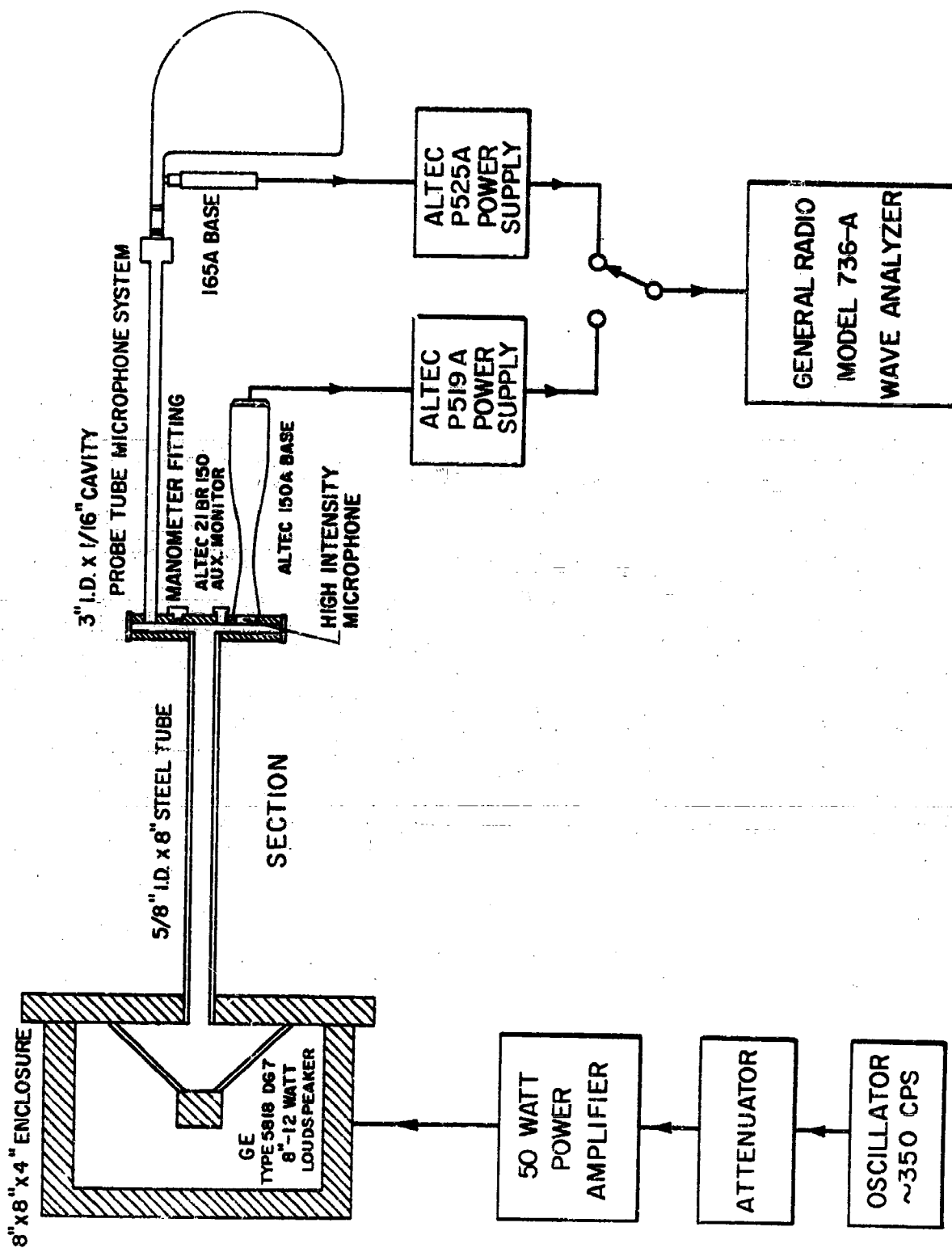


FIG. A.10 RESONATE TUBE USED FOR DISTORTION MEASUREMENTS ON PROBE TIPS

one Altec 21 BR series microphone, one high intensity microphone (built by and on loan from WADC), one probe tube tip and one manometer fitting, all parallel to the inner face of the cavity.

The 8 in. loudspeaker was driven at the system's resonant frequency of 350 cps. The blast microphone was used throughout as a monitor of sound pressure inside the cavity. In order to check for uniformity of sound pressure, measurements were also made at lower levels comparing the blast microphone and the 21 BR 150 microphone with the probe tube in place and with the probe tube removed, leaving an opening in the cavity. Under either condition, the pressure at the two microphones was the same well within an experimental error of ± 1 db and, therefore, the pressure throughout the inner face of the cavity was taken to be constant for all measurements.

As an absolute calibration of the high intensity microphone a manometer was attached to the cavity via a 0.020 in. diameter, 1/4 in. long hole in the manometer fitting mentioned above. With the power amplifier adjusted for the sound pressure in the cavity necessary to produce a radiation pressure of 3.15 in. of water as measured by the manometer the high intensity microphone indicated a sound pressure of 176.0 db. This radiation pressure corresponds to a calculated sound pressure level of 176.5 db and thus indicates a satisfactory agreement between high intensity microphone calibration and radiation pressure.

The harmonic distortion at the electrical output of the high intensity microphone was measured versus sound pressure level in the cavity by determining the amplitude of the first five harmonics of the 350 cps fundamental using a 4 cps wide wave analyzer and summing these harmonics. This curve is shown in Fig. A-11

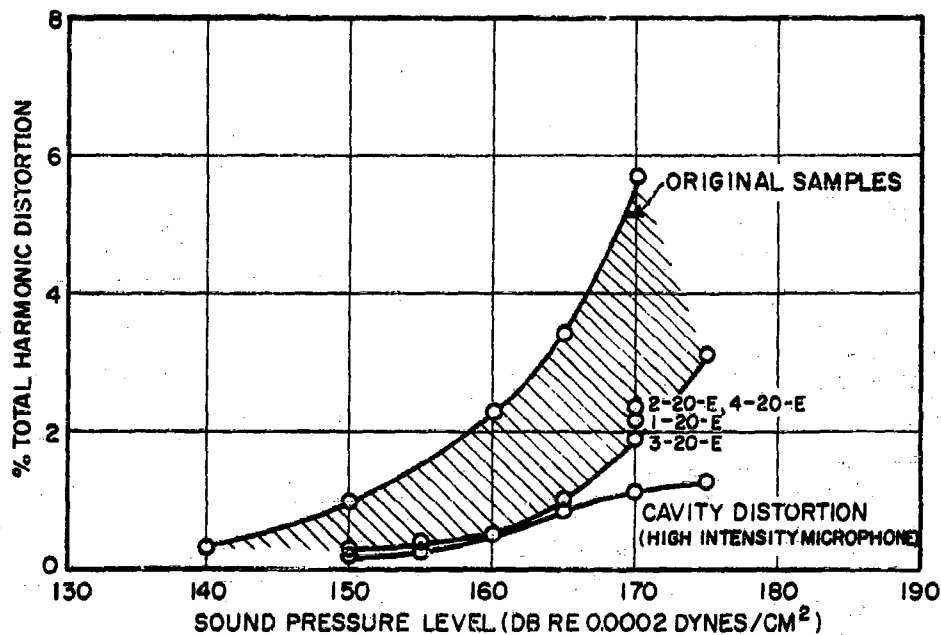


FIG. A.11 MICROPHONE DISTORTION AT 350 CPS FOR TYPE 1/16" THICK SINTERED STAINLESS-STEEL TIPS SHOWING SPREAD AMONG SAMPLES TESTED. DISTORTION INDICATED AT 170 DB FOR TIPS SUPPLIED

and indicates that the total distortion in the cavity, including any distortion present in the high intensity microphone itself, is approximately 1.2 per cent for a sound pressure level of 175 db in the cavity.

The internal impedance of the cavity was determined for the fundamental and each of the harmonic

frequencies by noting the change in cavity pressure for a change in tip impedance of the probe tube inserted into the cavity. This internal impedance was found to lie between approximately 0 and 3 pc for the different harmonics of the fundamental. Since these values of

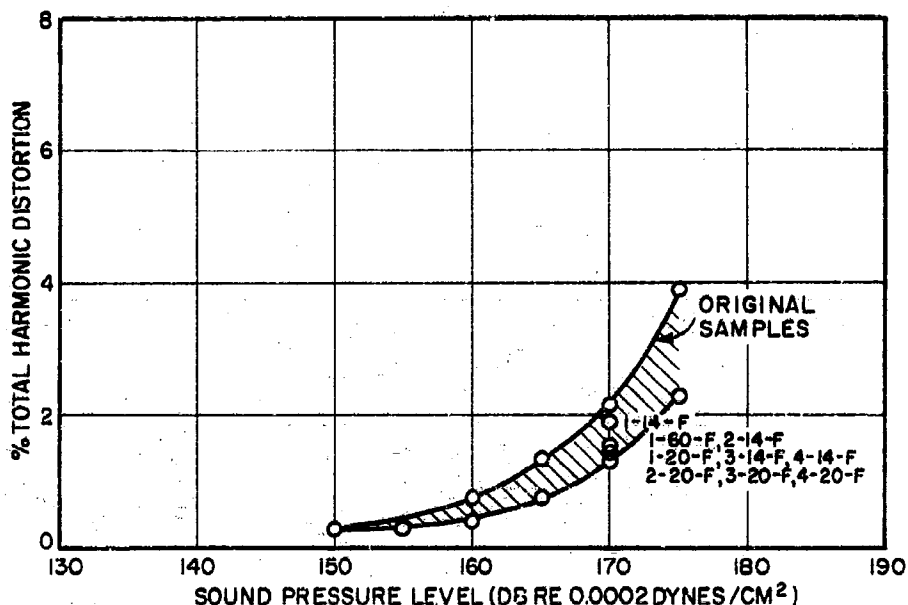


FIG. A.12 PROBE MICROPHONE DISTORTION AT 350 CPS FOR TYPE F 1/8" THICK SINTERED STAINLESS STEEL TIPS SHOWING SPREAD AMONG SAMPLES TESTED. DISTORTION INDICATED AT 170 DB FOR TIPS SUPPLIED

internal impedance are small compared to the resistance of the probe tip, the probe tip distortion as measured in this cavity should correspond closely to that obtained in free space.

Figures A-11 and A-12 show the results of distortion measurements on the Type E and Type F sintered stainless

steel probe tips respectively. It will be noted that, especially in the case of the Type E material, there is considerable spread in distortion characteristics among probe tips of nominally the same type.

On the basis of the distortion characteristics for the original samples tested, it was deemed advisable to supply both Type E and F probe tips in order to make the probe microphone system useful over as wide a range of sound pressure levels as possible. As can be seen from Fig. A-11, however, the four Type E probe tips supplied have distortion characteristics that are much superior to those of the original Type E samples. They are, in fact, comparable to the Type F probe tips. Therefore, only one curve (Fig. 3) of probe tip distortion versus sound pressure level was given in the operating instructions for use with both Type E and F probe tips.

It should be noted, however, that the Type E material in general has a higher distortion than the Type F for a given sound pressure level and Fig. 3 cannot be assumed to apply to any Type E probe tip other than the four supplied.

APPENDIX B

HISTORY OF THE PROBE TUBE MICROPHONE DEVELOPMENT

The following discussion is intended to acquaint the reader with the approach followed in the probe tube microphone development program. Some of the problems encountered are discussed and the reasoning leading to the final design is given.

Seven main components of the system are discussed in the following order:

1. probe tube tip
2. probe tube
3. coupling between probe tube and termination unit
4. transition from circular to rectangular cross section
5. spiral termination
6. microphone used as sensing element
7. pressure release system

B-1. Probe Tube Tip

A. Materials for Use in the Tip. The probe tube tip had to operate satisfactorily when mounted flush with the wall of the test cell or eductor tube. Therefore, it had to meet the rather stringent requirements of having a relatively high flow resistance which was linear over a wide range in pressure, resistance to high temperature conditions as well as mechanical smoothness and strength.

It was desirable that the tip have a high flow resistance so that it would not change the acoustic impedance of the test cell wall appreciably. The size of this flow resistance directly affected the sensitivity of the probe tube microphone system, and it was therefore important that the flow resistance of the tip be independent of sound pressure level over the operating range of the microphone system.

The probe tube tip had to be capable of operation at temperatures as high as 900°F and therefore had to present a flow resistance which was linear as well as oxidation and corrosion resistant at these high temperatures. It was necessary for the tip to present a smooth outside surface so that it would not interfere with the boundary layer into which it was placed. The probe tube and tip

had to be sufficiently rugged as to maintain their sensitivity calibration under field conditions including mounting in a test cell wall.

The following materials were tested in order to determine their applicability to the tip:

1. Poroloy*, a porous material obtainable in stainless steel as well as other materials.
2. Sintered stainless steel**
3. A single small hole.
4. Steel needles packed tightly together.

Several samples each of the Poroloy and sintered stainless steel materials were tested by flow-resistance measurements; two different diameter single holes and one set of packed needles were also tested. The flow resistance measurements were made over a pressure range 0.5 to 10 in. of water. These static pressures correspond to rms sound pressure levels of 136 db and 162 db re 0.0002 dynes per cm², respectively. On the basis of these flow resistance measurements, the most promising samples were mounted

* This material was supplied by Poroloy Equipment, Inc., 12270 Montague Street, Pacoima, California.

** This material was supplied by Micro Metallic Corp., Glen Cove, New York.

in the high-intensity test chamber, and total harmonic distortion measurements versus sound pressure level were made at 350 cps. Figure B-1 gives the flow resistance and total distortion measurements for three of the samples tested. It can be seen from this figure that the flow resistance, although giving a qualitative picture of the range in sound pressure level for which serious distortion is likely to occur, does not present the behavior in nearly so quantitative a fashion as the total distortion measurements.

For the test of packed needles, 122 0.029 in. diameter steel sewing needles were packed into a 3/8 in. inside diameter tube. The resulting flow resistance of approximately 100 rayls varied approximately 25% over the pressure range from 0.5 in. to 10 in. of water. Although this flow resistance change was not very much greater than that of the Type E stainless steel sample shown in Fig. B-1, the packed needles were inferior to the sintered stainless steel in the following three ways:

1. Fabrication of the tip was much more difficult and less likely to produce units possessing uniform characteristics.

2. There was no simple way known to insure that the needles would not loosen and change their relative positions due to temperature cycling and mechanical vibration.
3. The points of the needles presented a considerably rougher exterior than the surface of the sintered stainless steel or Poroloy. Therefore, more disturbance of the boundary layer might be experienced in application of the probe tube to a test cell wall.

Figure B-2 gives the total harmonic distortion at 350 cps versus sound pressure level for a single hole, a Poroloy tip and sintered stainless steel tips. It can be seen that the Type E, 1/16 in. thick sintered tip is satisfactory for sound pressure levels up to 160 db, while the Type F, 1/8 in. thick tip is satisfactory for levels in excess of 170 db. These two tips were therefore chosen for use in the final probe microphone system.

The Type E was considered completely satisfactory for most measurements as it met the specifications set forth for the probe tube microphone (i.e., linear to 160 db), and the Type F tip, while sacrificing approximately 11 db in sensitivity, permitted the use of the microphone to levels in excess of 170 db.

B. Method of Attaching Tip to Probe Tube. It was necessary to attach the tip to the probe tube by a method which would satisfy the following requirements:

1. There had to be an airtight seal between the tip and probe tube.
2. The acoustic properties of the tip had to be unaffected.
3. The method of attaching had to be vibration-proof and not affected by temperature cycling as well as continued high-temperature operation.
4. The probe tube had to have a smooth outer surface, that is, no surfaces extending beyond the outside diameter of the tube, so that it could be mounted through a hole in the test cell wall with the minimum difficulty.

The methods tried for mounting the probe tube tip were:

1. Clamping the tip with a screw-on collar-like clamp
2. Cementing the tip into a machined recess using high-temperature cement, and
3. Welding the tip to the probe tube using a shielded electric arc.

After extensive testing, clamping methods proved unsatisfactory because of the unavoidable leaks around the edge of the tip and the inherent weakness to loosening by vibration. The clamp was also of larger diameter than the outside diameter of the probe tube and made mounting through a hole more difficult than was considered satisfactory.

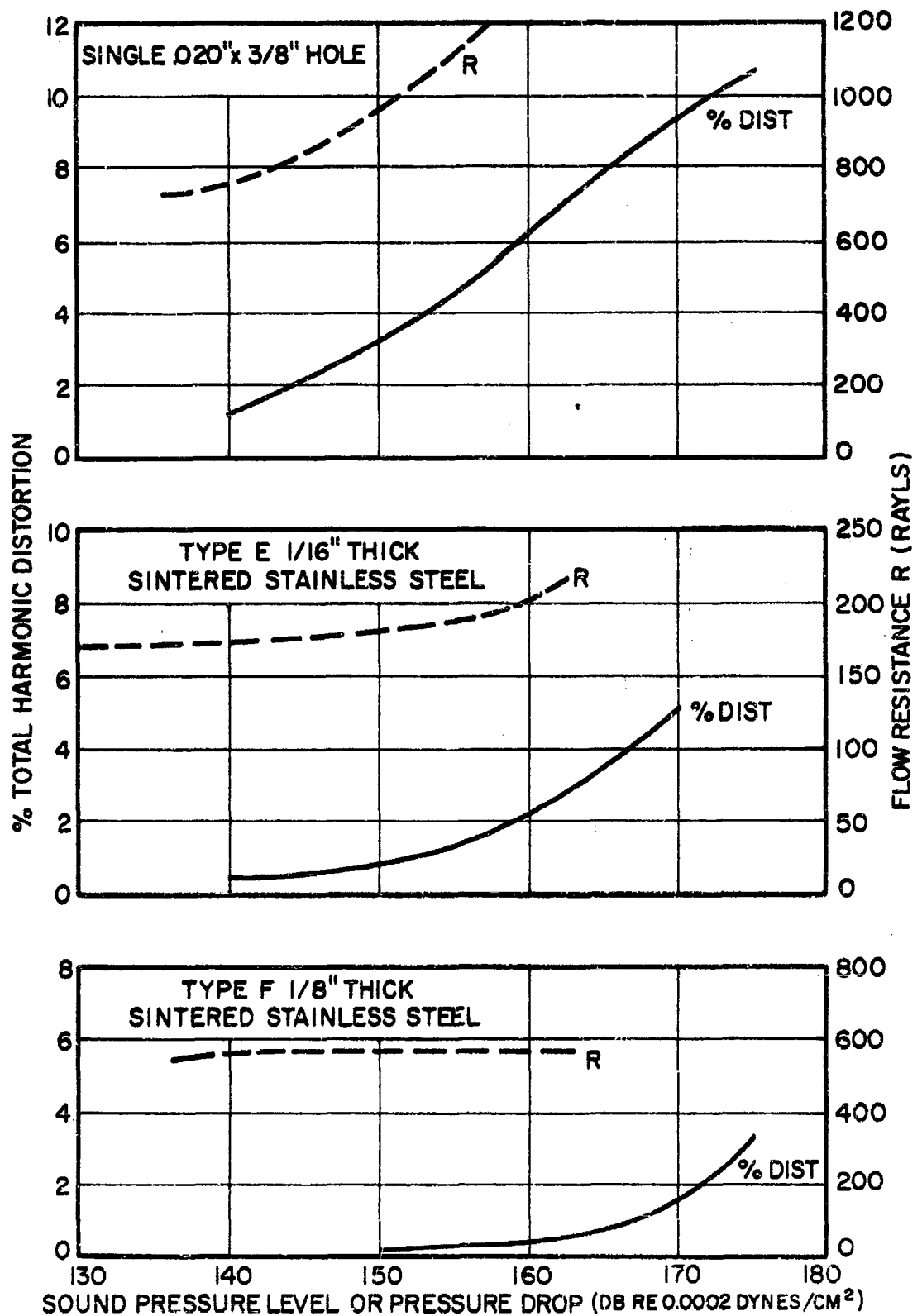


FIG. B.1 FLOW RESISTANCE AND DISTORTION MEASUREMENTS AT 350 CPS ON THREE TYPES OF PROBE TIPS

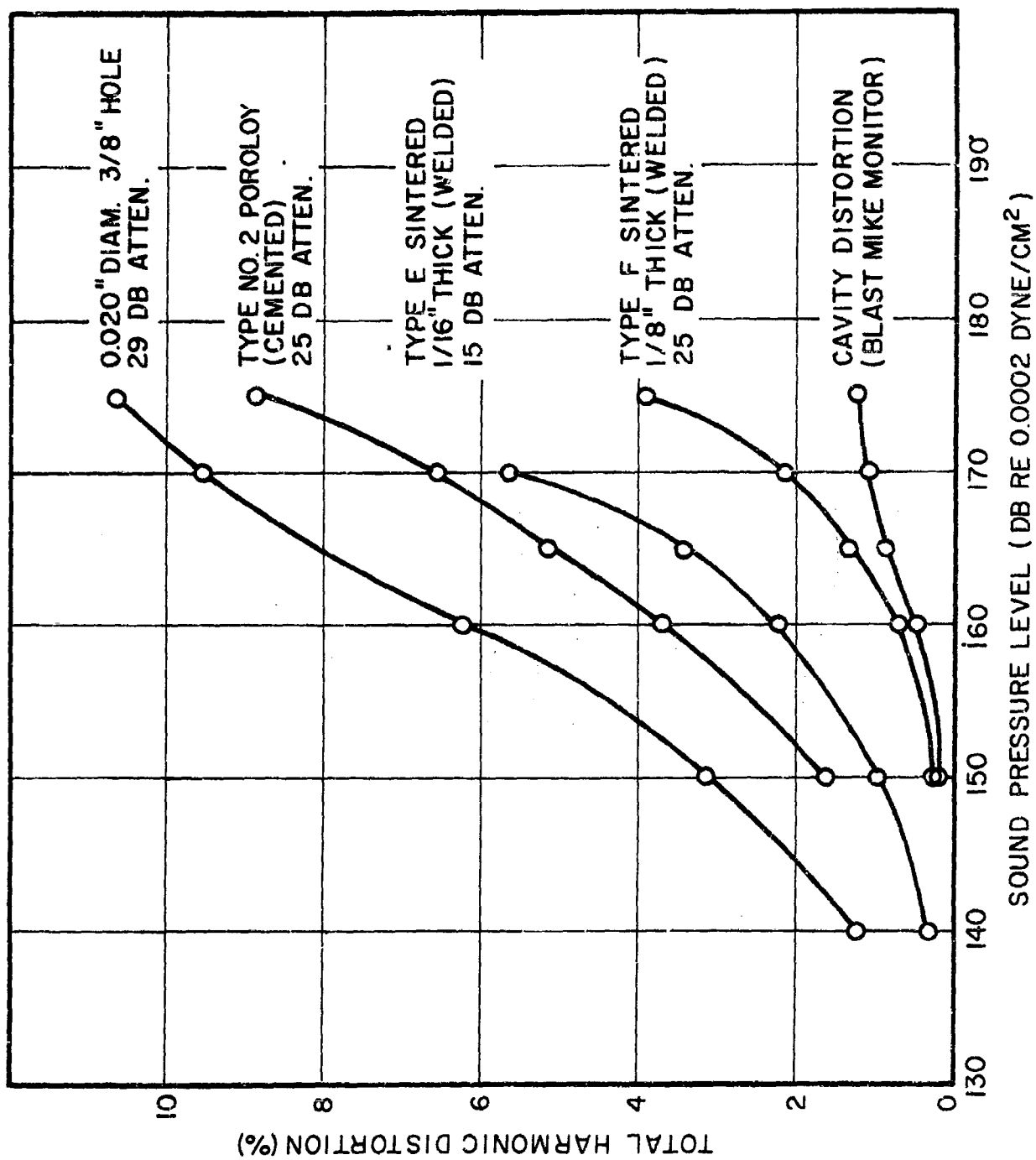


FIG. B.2 PROBE MICROPHONE DISTORTION AT 350 CPS FOR VARIOUS TIPS

Several samples of both Poroloy and sintered stainless steel tips were cemented into recesses in the probe tubes using Sauereisen high temperature cement. This method provided the required airtight seal, preserved the acoustic properties of the tip, and maintained the uniform outside diameter of the probe tube. The method also promised to be vibration and heat-cycle proof, although tests were not made of these properties. The method of attaching the tips by cementing appeared to be satisfactory and would probably have been used if no better method had been found. However, it was desirable to avoid the somewhat brittle seal provided by the cement, and therefore the possibility of welding the tip in place was investigated.

Several tips of Poroloy were welded onto the probe tubes by a shielded arc by a local welding company. These tips were not satisfactory because the heat generated in the welding process significantly changes the flow resistance of the material. In the process of discussing their material with Microi Metallic Corporation, it was learned that they employed welders trained in welding sintered stainless steel, and they undertook the job of welding disks of their sintered stainless steel to the probe tubes we provided. Their welding techniques proved satisfactory, and the flow resistance of the welded tips was only slightly greater than the flow resistance of the stock from which they were made. Because of its extreme mechanical reliability, the welding technique was adopted for mounting the probe tips to the tubes.

C. Wind Noise Considerations. The self-noise generated by the passage of an air stream past the surface in which the probe tube tip was mounted was given consideration. No measurements were made to determine this self-noise, although the problem was discussed at length with our consultant in aerodynamic problems, Dr. Shapiro*.

The tips selected were very smooth and entirely comparable, for example, with the surface of an eductor tube, and, in general, the tips were to be mounted flush with the surface of a wall. Dr. Shapiro pointed out that therefore the tip would be at a boundary layer of the order of $1/4$ in. in thickness and the self-noise due to wind velocity should be negligible.

B-2. Probe Tube

A. Method of Cooling. The probe tube served to connect the tip with the remainder of the probe microphone system and therefore had to operate with the temperature of the inside of the test cell wall at one end and approximately room temperature at the other. For this reason, serious consideration was given the problem of cooling the probe tube.

* Dr. Shapiro is a professor of Mechanical Engineering at the Massachusetts Institute of Technology and author of the book, The Dynamics and Thermodynamics of Compressible Flow.

Plans were made at first for cooling the tube by means of a water jacket surrounding the tube through which water would be circulated continuously. However, from discussing the problem with other groups engaged in high temperature work, it was learned that Inconel tubing was capable of supporting quite large temperature gradients even when surrounded by comparatively still air.

Therefore, calculations were made to determine the temperature gradient to be expected in a tube of Inconel with the temperature of one end maintained at a high value and the cooling by means of radiation only. These calculations indicated that, for the emissivity and thermal-conductivity of the Inconel tube, a temperature drop from 900°F at one end to approximately 40°F above ambient at the other end could be expected in a distance of approximately 8 in. along the tube. Consideration was given to the effect that different temperature gradients might have upon the sensitivity of the probe tube microphone system. As reported in the appendix on testing, measurements were made of the sensitivity of the system versus frequency for three different temperature gradients:

1. the normal gradient obtained by radiation cooling,
2. a gradient considerably more gradual, and
3. a considerably steeper gradient.

These tests indicated that the sensitivity of the system was relatively unaffected by temperature gradient.

Since the tests just discussed indicated that the desired gradients could be obtained within a few inches of probe tube length, and the variations in these gradients to be expected by different ambient conditions would not appreciably affect the sensitivity of the system, it was decided that water cooling was unnecessary and that natural air cooling could be used.

B. Size of Tubing. The main limitation on the inside diameter of the probe tube was considered to be the high frequency attenuation due to viscous effects in the boundary layer. These effects were computed to be approximately 1 db/ft at 5000 cps for a tube of 3/8 in. inside diameter. The attenuation increases as the square root of the frequency.

A 3/8 in. inside diameter was therefore considered satisfactory from the standpoint of high frequency attenuation. Calculation of the cross modes to be expected in this size tubing indicated that they would fall above the useful expected range of 20-10,000 cycles. However, we were unable to obtain Inconel tubing in smaller sizes than 1/2 in. inside diameter and, therefore, the original prototype of the probe tube microphone system was designed for 1/2 in. inside diameter tubing.

Measurements made on the 1/2 in. inside diameter probe tube verified the original calculations and indicated that it would be quite permissible to use a 3/8 in.

inside diameter if the tubing could be obtained. The primary reason for desiring the 3/8 in. inside diameter was the significant reduction in the size of the termination unit that could be obtained. The spiral groove in the termination unit had to have the same cross-sectional area as that of the probe tube and, therefore, a reduction from a 1/2 in. to a 3/8 in. probe tube inside diameter would permit a reduction to almost half the cross-sectional area of the terminating duct.

Through correspondence with the Development and Research Division of the International Nickel Company we succeeded in locating a re-draw mill capable of making a special run of 3/8 in. inside diameter Inconel tubing. Therefore, after the initial tests were completed on the prototype, the final model was designed to use 3/8 in. inside diameter tubing.

The reduction in bulk effected by this change in tubing size can be noted by comparing the original prototype termination unit whose diameter was 10-1/2 in. and weight 9.3 lbs with the final model having a diameter of 8 in. and a weight of 3.2 lbs.

B-3. Coupling Between Probe Tube and Termination Unit

A. Coupler. The device used for coupling the probe tube to the termination unit must:

1. preserve a constant cross sectional area through the joint,
2. maintain an airtight seal, and
3. permit easy removal and attachment of the tube to the termination unit.

A simple collar was originally used for this purpose but was found to be unsatisfactory. The constant cross-sectional area was preserved by the collar but field experience showed that it was difficult to maintain the collar tight without some sort of special seal and that it was highly desirable to be able to mount the probe tube securely in a test cell wall and then attach it to the terminating unit without having to rotate either member. For this reason, the coupler was redesigned in the form of a union which fulfilled the three requirements listed above and permitted both members to be stationary while being attached. An O-ring was incorporated into the union to insure an airtight seal.

B. Vibration Break. It was felt to be desirable to provide some means for reducing the level of mechanical vibration transmitted from the probe tube to the terminating unit. For example, if the probe tube were mounted in the wall of a structure which was vibrating, these vibrations, if transmitted to the terminating structure, might introduce signals into the output of the condenser microphone by way of the microphonics in the preamplifier.

A rubber vibration break was therefore designed for insertion between the probe tube and termination unit. The usefulness of this vibration break was demonstrated in a test in which the side of the probe tube was held in contact with the air intake of an automobile carburetor. With the vibration break in place (using a $\frac{1}{2}$ in. unsupported length of rubber tubing) the output of the probe tube microphone system corresponding to the sound pressure at the probe tip was approximately 15 db above the output caused by mechanical vibrations of the probe tube (as determined by use of the dummy probe tube). Removal of the vibration break reduced "signal-to-vibration pickup" ratio approximately 6 db.

However, there can be situations in which the vibration break would be a disadvantage rather than an advantage and, therefore, the system was designed so that it could be readily used with or without the vibration break in place. For example, if the probe tube were moved axially with the vibration break in place it would appear that the probe tube would act as a piston compressing and expanding the air inside the probe tube and termination units and thereby creating a pressure at the microphone and an undesired output. In order to provide as flexible a field instrument as possible, the dummy probe tube and vibration break were included in the complete probe tube microphone system and the discussion given in the operating manual was intended to help the user to determine when the probe tube should be used with the vibration break and when it should be used without it.

C. Locating Stop Collar. As the result of field tests with the original prototype system, it was suggested that some means of pre-setting the depth of penetration of the probe tube into a hole, such as the hole through a test cell wall, would be highly desirable. This device could be used, for example, to determine that the probe tube would be flush with the inside of the wall when installed from the outside without having to check the inside of the wall. It would also be very useful when the probe tube was mounted through a ceiling, since then it could carry the weight of the probe tube. Therefore, a stop collar was designed which slides along the probe tube and, by means of two set screws, can be clamped at any desired point.

B-4. Transition from Circular to Rectangular Cross Section

A. Consideration of Uniform Transition. In order to be able to make the terminating duct of rectangular cross section, thus facilitating the location of the condenser microphone, as well as manufacture and filling of the duct with absorbent material, a transition section was necessary. When designing the original prototype, it was thought necessary to make a completely uniform transition from the round circular cross section of the probe tube to the rectangular cross section desired for the termination unit. After discussing the problem with several coppersmiths and investigating the possibility of using electro-forming processes such as those used in wave guide sections, it was concluded that neither source of supply was satisfactory for this application. The coppersmiths were unwilling to undertake the fabrication of a unit so unusual in shape and

the electro-forming processes proved to be very expensive for non-standard sizes.

In order that the original prototype would not be held up unduly for this one component, a handmade transition piece was used. This section was made from soft copper tubing and formed into shape on dies inserted from each end. The resulting section was then soldered into mounting flanges and located between the termination section and the probe tube.

B. Abrupt Change from Circular to Square Cross Section Provided Solution. The transition section described above proved entirely satisfactory in the original prototype so far as acoustical performance was concerned, but left a great deal to be desired from a standpoint of mechanical strength and ease of fabrication. At this point, it was decided to investigate the possibility of changing abruptly from the circular cross section of the probe tube to a square intermediate cross section and then progressing by sloping straight machined surfaces to the desired rectangular cross section*.

The transition section designed along these lines produced a reduction in cross sectional area from full

* This technique was observed to work satisfactorily in a spiral termination designed by Dr. Leonard.

area to 92 per cent of full area at the point where the circular cross section changes abruptly to square. The square part of the transition had the same cross sectional area as that of the probe tube and, by expanding in one direction and compressing in the other, changed to the desired rectangular cross section while requiring nothing but straight line machining operations. The maximum deviation from the probe tube cross sectional area was computed to occur approximately half-way down the transition section (i.e., half-way between the rectangular and the square ends) and at this point the cross sectional area is approximately 8 per cent greater than that of the probe tube.

C. Advantages of Locating the Condenser Microphone in the Transition Piece. In the original prototype the transition section was one piece, the unit for attaching the condenser microphone another and the spiral termination was a third piece. These three units were then attached with screws and gaskets to form a complete unit to which the probe tube was attached. In order to consolidate the system and make it more compact and readily adapted to field use, the transition section and microphone mounting points were combined as integral parts of the termination unit.

The combination transition section and microphone holder was then fitted into a notch machined into the supporting member. In this way, the member connecting the probe tube to the termination section was not

weakened by the hole for the microphone attachment. This design had the additional advantage that only a small piece, i.e., the transition section, must be replaced if the threads used for mounting the condenser microphone become damaged or if it is desired to mount a slightly different type of microphone.

B-5. Spiral Termination

A. Design. The general principal of operation of a spiral termination, that is, the idea of terminating the probe tube in a long duct filled with absorbent material which is formed into a spiral for compactness, was known from Dr. Leonard's work*. However, there were no design details available and these had to be worked out on the prototype model. It was necessary to make the groove deep enough (i.e., the dimension normal to the surface of the termination unit) to accomodate the face of the condenser microphone. It was also desirable to make the groove as deep as possible in order to reduce the required diameter of the probe termination unit. Since the cross sectional area of the terminating duct was set to be equal to the cross sectional area of the probe, increasing the depth of the groove resulted in a decrease in the groove

* R. W. Leonard, "Resistively Terminated Probe Microphone," abstract of paper contributed to the 42nd meeting of the Acoustical Society of America, October 23-25, 1951, Journal of the Acoustical Society of America, 24, p. 113 (January 1952).

width and, therefore, a decrease in the required radius of the termination for a given length of duct.

A tapered spiral (i.e., one in which the depth changed from full value to zero as the spiral progressed toward the center) was used in the original prototype. It was thought that this type of spiral would provide better matching of the sound waves to the absorbing material and would therefore provide more efficient utilization of the absorbing material. However, measurements made on this prototype indicated that the tapering was not necessary and the final design used a spiral groove of constant depth.

The depth of the groove in the final model is such as to have its first mode at approximately 12 kilocycles. The spacing or "land" between the adjacent grooves was set at 1/8 in. in order to provide sufficient rigidity for the required machining operations.

The method of mounting the probe tube termination unit in the field was discussed at length both with representatives of Wright Field and members of our own group who had used the original prototype on field tests. It was concluded that while actually holding the termination might be the only satisfactory alternative occasionally, in general it would be either mounted on a tripod or suspended from one or more cables. In order to facilitate either of these mountings in as flexible a manner as possible, four one-quarter inch-20 threaded

holes were provided in the termination unit, one through the center of the unit normal to the surface and three others around the edge of the unit. These holes will accommodate either standard tripod mounting attachments or eye-bolts for use in attaching cables. Handles could also be screwed into these holes if desired.

B. Manufacture. Several machine shops considered the job of machining the spiral groove in the original prototype. However, only one of these shops was willing to undertake such an unusual machining operation. Although this shop did a satisfactory job on the original prototype, they encountered so many unexpected difficulties that they asked a considerably higher price for machining the four final units in spite of the simplifications resulting from a change from tapered to constant cross section.

It was therefore deemed advisable to set up for the machining of the spiral groove in our own machine shop. The special attachments to permit the cutting of the desired spiral groove on our Bridgeport milling machine were designed. These attachments provided drive for the rotary turntable and longitudinal table feeds synchronized in such a way as to provide the desired pitch in the milled groove. The power drives were taken from a variable speed d.c. motor so that the linear cutting speed could be held constant rather than the angular speed as would otherwise have resulted. These special attachments operated satisfactorily and permitted completion of the spiral groove machining with a lower total cost than would have been obtained from the outside company.

C. Absorbing Material to Line Spiral Termination. A degree of compromise was found to be desirable in the selection of material to line the termination duct. A material such as lightweight Aerocor provided a high degree of damping for standing waves and the response between mid-frequency and very low frequency regions was fairly uniform. However, the use of this type of material resulted in a comparatively low value of R_1 in the very low frequency equivalent circuit (see discussion and Fig. A-2 in Appendix A) and, as can be seen in Fig. B3, f_1 was therefore rather high. On the other hand, a denser material, such as heavy felt, decreased f_1 but also provided less damping for the standing waves.

A feltlike material, Weberil 2801*, was chosen as a compromise between these two extremes. Two thicknesses of the 1/16 in. thick material were sewed together and then a 10 ft long wedge tapering from 9/16 in. wide to zero was cut and fitted into the spiral groove. The tip of the wedge was secured near the beginning of the spiral with a drop of cement.

The response of probe microphone system number one with the Weberil duct lining is also shown in Fig. B-3. This response was obtained as a comparison between the response of probe system number one using a 165A base and associated

* Weberil was supplied by the Kendall Mills, Walpole, Massachusetts.

power supply and the response of another 21 BR 150 microphone and 165A base. Therefore, to the extent that the two condenser microphone systems were the same, Fig.B-3 does not include the response of the 21 BR 150 microphone and associated amplifier.

B-6. Microphone Used as Sensing Element

A. Acoustic Considerations. The transducer relating the pressure in the probe tube duct to the output electrical voltage should lend itself to mounting in the duct wall without interfering with the cross sectional area of the duct or the boundary impedance. As much as possible, the microphone should also have a flat pressure response over the range of interest.

Both these requirements were met satisfactorily by condenser type microphones. These microphones have a relatively high mechanical impedance at their diaphragm and possess the desired uniformity of pressure response.

B. Mechanical Considerations. As discussed earlier the width of the microphone played an important part in the determination of the depth of the spiral duct and, therefore, a microphone having a reasonably small width (in this case, the order of 0.6 in.) was desired.

In order to reduce the effective flanking and to permit the operation of the probe tube at reduced pressures, the microphone had to seal tightly into the duct. Although there were several ways that this seal might have been obtained, it was decided to use the Altec 21 BR series microphone which is threaded and, therefore, lends itself well to such sealing.

With reference to Fig. B-2 it will be noted that for the probe tip 3 per cent distortion point, the sound pressure at the condenser microphone would be between 145 and 150 db when either the Type E or the Type F tips were used. Therefore, the Type 21 BR 150 microphone was considered satisfactory since its own overload point lies between 155 and 160 db. The 21 BR 180 microphone was considered for this application but was deemed less desirable because its reduced sensitivity made electrical noise and preamplifier microphonic problems more severe.

C. Preamplifier. The preamplifier used with the condenser microphone was selected from those available commercially on the basis of low microphonic level and reliable operation over a wide range of humidity conditions. The latter requirement seemed to indicate the need for a grid resistor to insure the correct operation and biasing even with microphone leakage present. However, the least microphonic of the preamplifiers available, the Altec 165-A "Lipstick" preamplifier, did not appear to provide either the physical space or the electrical connections

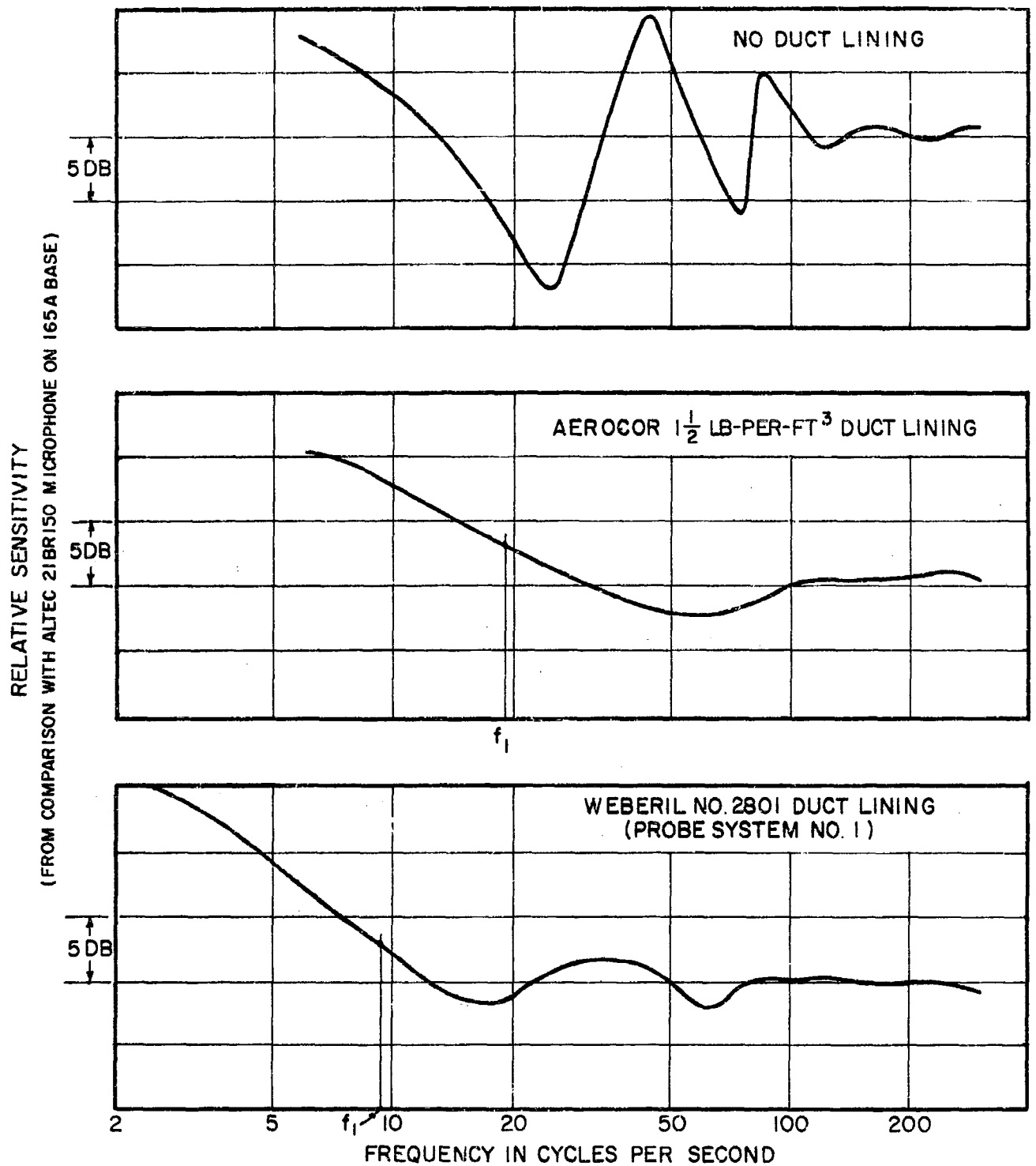


FIG.B.3 PROBE MICROPHONE SENSITIVITY VS. FREQUENCY FOR
VARIOUS MATERIALS LINING THE TERMINATING DUCT

necessary for the insertion of a grid resistor. In order that the probe microphone system might be useful over as wide a range of field conditions as possible, two Altec Type 165-A low microphonic preamplifiers were provided for those applications in which the preamplifier must be in a high sound or vibration field, and two Altec Type 150A bases with 22 megohm grid resistors added were provided for use where microphone leakage poses a problem. As a further check on the preamplifier performance, phone jacks were added to each of the four preamplifier power supplies so that the preamplifier cathode current could be monitored if desired.

B-7. Pressure Release System

In order that the tip of the probe tube might be located in a high altitude wind tunnel in which the static pressure might be as low as 0.2 atmospheres while the microphone and termination unit were located in a room at atmospheric pressure, it was necessary to insure that the condenser microphone would operate satisfactorily under these conditions. This problem was referred to the Altec Lansing Corporation and they felt that it would be necessary to maintain the front of the diaphragm and the back of the back plate of the condenser microphone at the same static pressure. They said that normally present leakage would insure rapid equalization of the pressure between the back of the diaphragm and the back plate.

The design of a system to transmit the static pressure existing at the center of the spiral termination to the back of the condenser microphone was therefore undertaken. A pressure release cavity, similar to the one employed in the final model, was designated with the original prototype model. This cavity provided a sealed volume behind the condenser microphone which could then be connected via a plastic tube to the center of the termination. The cavity also permitted an electrical connection to be maintained from the condenser microphone to the preamplifier. In the field testing of the original prototype, the plastic tube connecting the pressure release cavity to the center of the spiral proved to be one of the weak points mechanically. In the final model, therefore, a sealed duct across the back of the termination unit was provided to transmit the static pressure to a point near the pressure release cavity so that only a very short length of plastic tubing would be required.

Difficulty was experienced in locating a plastic tubing of the desired small diameter which would still withstand a pressure differential of 0.8 atmosphere without collapsing. Such a tubing was finally located and the fittings used on the final model were designed in order to facilitate attaching and removing the length of tubing regardless of the angle at which the pressure release cavity happened to be when the threads tightened up.

PARTS LIST FOR PROBE MICROPHONE SYSTEMS 1-4

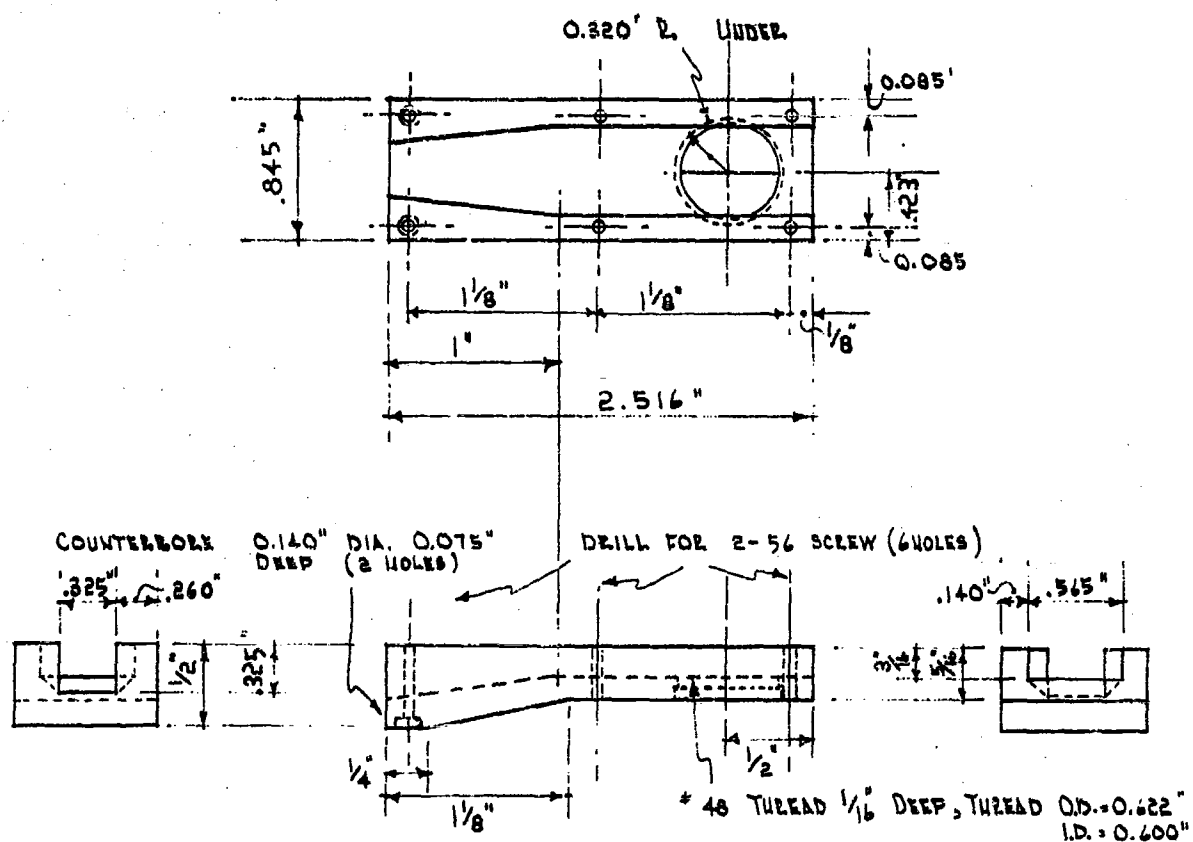
Part No.	Description	Supplier	Material	No. Required per System
1	O-Ring for Union	Parker Appliance Co. 17325 Euclid Avenue Cleveland, Ohio	Buna N Rubber	1
2	Vibration Break Tubing 3/8" I.D. x 3/32" wall	Greene Rubber Co. 99 Broadway Cambridge, Mass.	Gum Rubber	1
3	Pressure Release Tubing 1/16" press-fit tubing	Jassall Plastics Co. Kensington, Conn.	Vinyl	1
4	Cover Plate Gasket 0.010" thick #581 sheet	Garlock Packing Co. 80 Broad Street Boston, Massachusetts	Vegatable Fiber	1
5	Gasket Sealing Compound Garlock 101	Garlock Packing Co. 80 Broad Street Boston, Massachusetts	Neoprene	
6	Rubber Lining for Altec 150A Base Clamp 1/12" thick	Greene Rubber Co. 99 Broadway Cambridge, Mass.	Neoprene	0- Systems 1,2 1- Systems 3,4
7	Rubber Lining for Cable Clamp 3/16" I.D. x 1/8" wall	Greene Rubber Co. 99 Broadway Cambridge, Mass.	Neoprene	1- Systems 1,2 0- Systems 3,4
8	Screws for Transition Section 2-56 3/4" long fillister head	-----	Steel	6
9	Screws for Termination Cover Plate 6-32 x 1/2" flat head socket cap screws	-----	Steel	17

PARTS LIST FOR PROBE MICROPHONE SYSTEMS 1-4

Part No.	Description	Supplier	Material	No. Required per System
10	Screws for Preamp Holder and Cable Clamp 6-32 x 1/2" Allen Cap	-----	Steel	4
11	Washers for Preamp Holder or Cable Clamp 6-32 flat	-----	Steel	2
12	Condenser Microphone Altec 21 BR 150	Altec Lansing Co. 9356 Santa Monica Beverly Hills, Calif.	-----	1
13	Preamplifier Altec 165A Base	Altec Lansing Co. 9356 Santa Monica Beverly Hills, Calif.	-----	1- Systems 1,2 0- Systems 3,4
14	Power Supply for Altec 165A Base Altec P-525A	Altec Lansing Co. 9356 Santa Monica Beverly Hills, Calif.	-----	1- Systems 1,2 0- Systems 3,4
15	Rack Mount Case for Two Altec P-525A Power Supplies, Altec 11853	Altec Lansing Co. 9356 Santa Monica Beverly Hills, Calif.	-----	1- Systems 1,2 0- Systems 3,4
16	Preamplifier Altec 150A Base	Altec Lansing Co. 9356 Santa Monica Beverly Hills, Calif.	-----	0- Systems 1,2 1- Systems 3,4
17	Cable Set for Altec 150A Base Altec 153A Set	Altec Lansing Co. 9356 Santa Monica Beverly Hills, Calif.	-----	0- Systems 1,2 1- Systems 3,4
18	Power Supply for Altec 150A Base - Altec P519A	Altec Lansing Co. 9356 Santa Monica Beverly Hills, Calif.	-----	0- Systems 1,2 1- Systems 3,4

PARTS LIST FOR PROBE MICROPHONE SYSTEMS 1-4

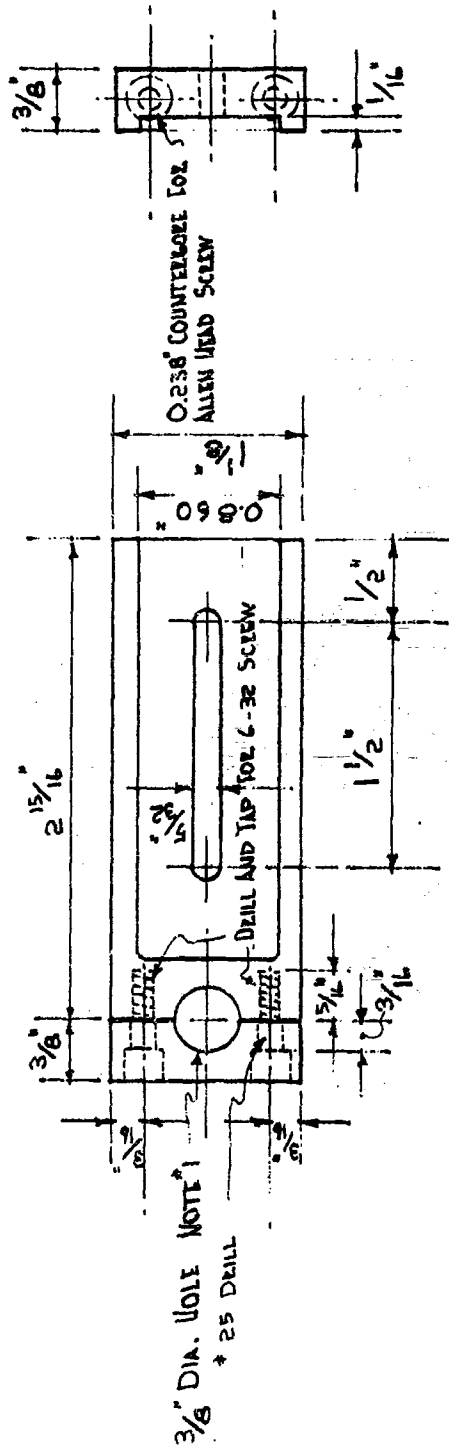
Part No.	Description	Supplier	Material	No. Required per System
19	Lining for Terminating Duct #2801 Non-Woven Cloth	Kendall Mills Walpole, Mass.	Cotton	1
20	Set Screws for Probe Tube Stop Collars 10-32 x 1/4" long	-----	Steel	2



TRANSITION SECTION FOR PROBE MICROPHONE

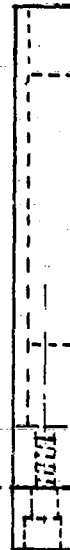
STOCK: 24 ST DURAL BLACK ANODIZED FINISH

TOLERANCES: FRACTIONS $\pm 0.01"$
DECIMALS $\pm 0.002"$



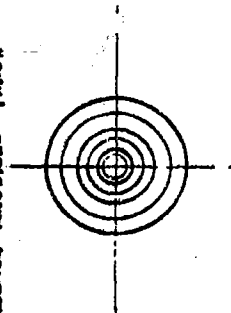
CUT OFF HERE WITH SLITTING SAW

NOTE 1 : BORE HOLE AFTER
CUT OFF OPERATION - FULLER
LINING (SPLIT TUBING PART 7)
CEMENTED INTO HOLE



CABLE CLAMP FOR USE WITH ALTEC 175A OR CL P1 BASES

Stock: 245T DURAL - BLACK ANODIZED FINISH
TOLERANCES FRACTIONS ± 0.01 "
DECIMALS ± 0.002 "



END VIEW

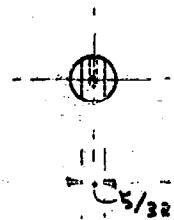
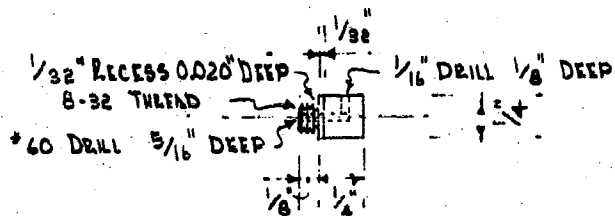
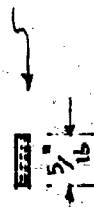
SECTIONS

ALL PARTS ABOVE MACHINED TO PRESS FIT TOGETHER
AND PRESS FIT INTO SOCKET

OTHER TOLERANCES: FRACTIONS ± 0.01
DECIMALS ± 0.002

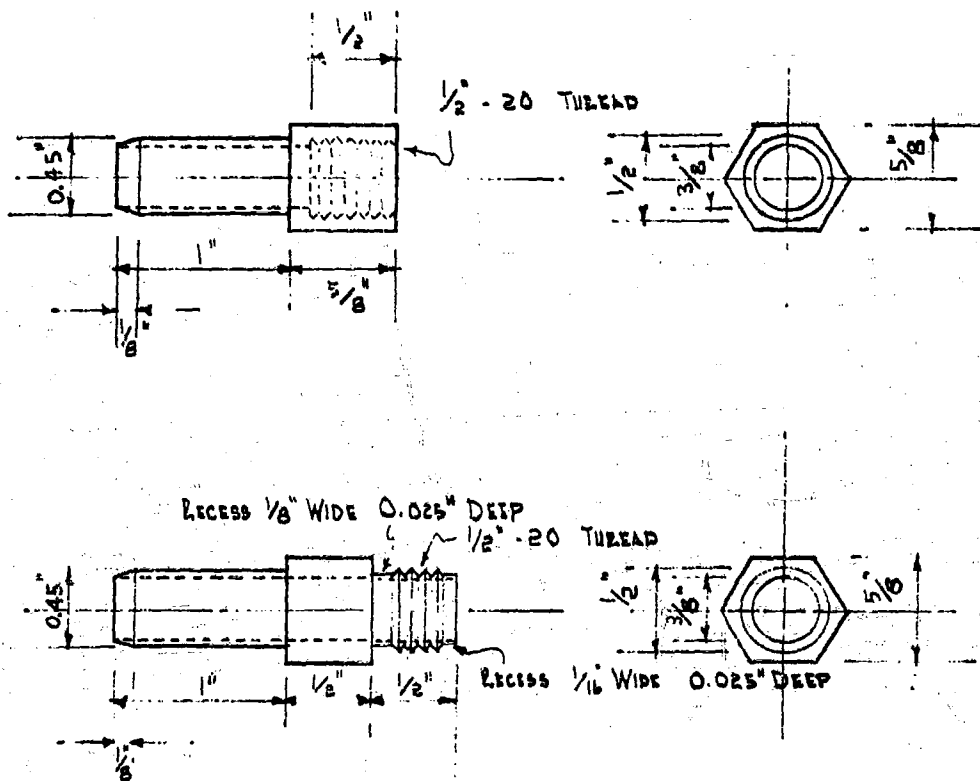
PRESSURE RELEASE FITTING

$\frac{1}{16}$ " HYPO TUBING PRESS FIT INTO
 $\frac{1}{16}$ " HOLE AND SOLDER.



PRESSURE RELEASE PLUG

STEEL
 BLACK PENETRATE FINISH



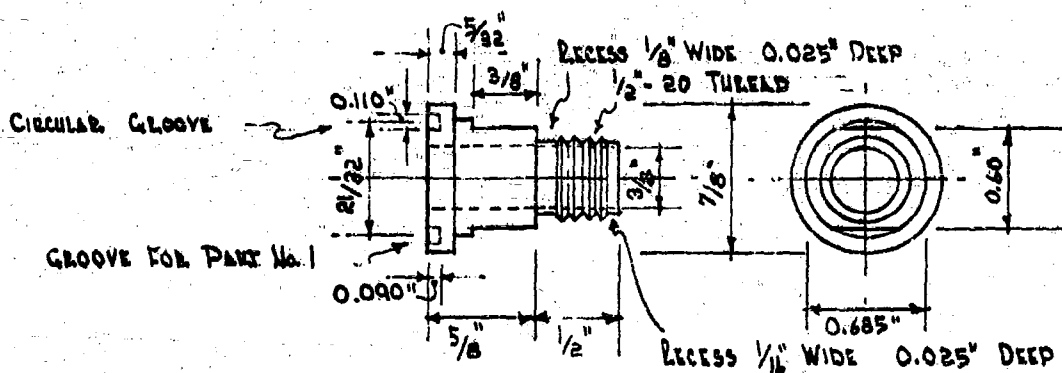
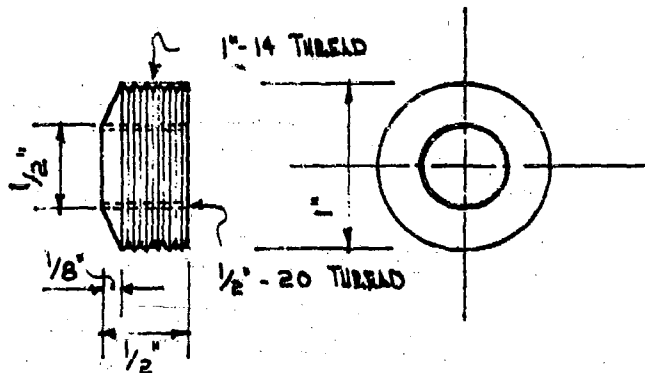
END PIECE FOR VIBRATION BREAK

STOCK 17S-T4 ALUMINUM HEX. ROD

BLACK ANODIZED FINISH

TOLEANCES: FRACTIONS ± 0.01 "
 DECIMALS ± 0.002 "

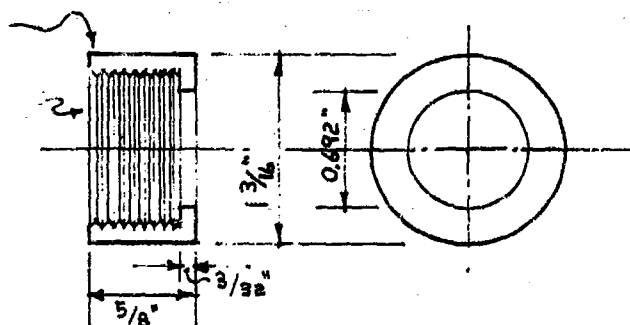
NO FINISH ON
THIS PIECE



KNURLED

1" - 14 THREAD

SECTION

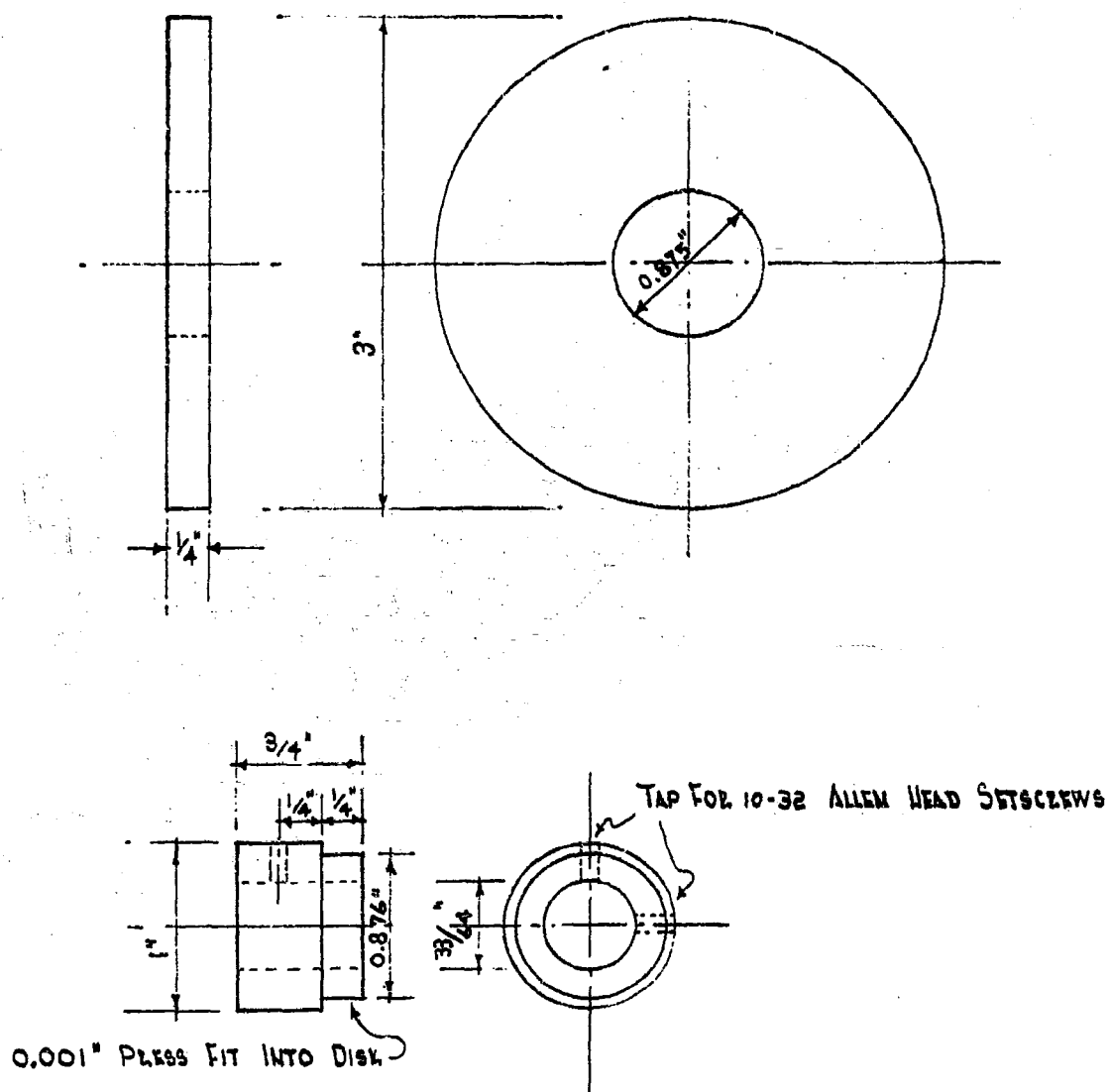


PROBE TUBE UNION

STOCK 249T ALUMINUM

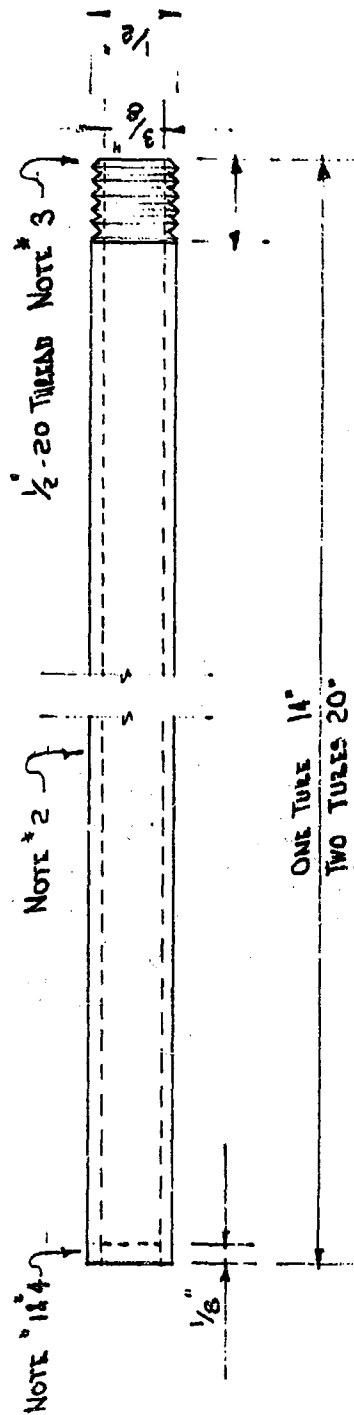
BLACK ANODIZED FINISH EXCEPT TOP PIECE

TOLERANCES: FRACTIONS ± 0.01 "
DECIMALS ± 0.002 "



PROBE TUBE STOP COLLAR
STOCK: STEEL
BLACK PENETRANT FINISH

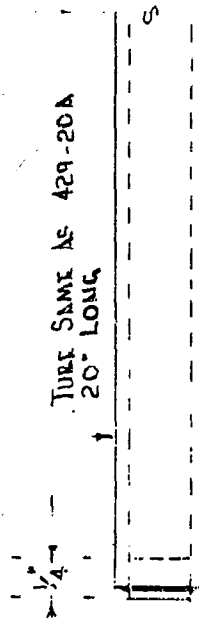
TOLERANCES
 FRACTIONS $\pm 0.01"$
 DECIMALS $\pm 0.002"$



NOTE 2: THREAD SEALED INTO UNION FITTING (TOP PRICE DWG. 429-18) WITH GASKET CEMENT (PART #5) AND END FACED OFF

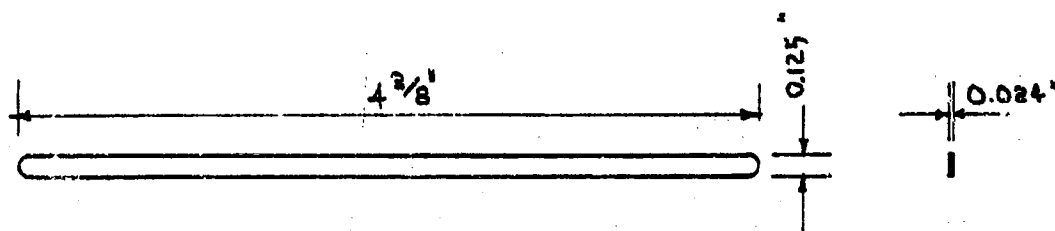
NOTE 4: 1/2" THICK DISK OF SINTERED STAINLESS STEEL TYPE F WELDED ONTO 20" TUBE

PROBE TUBE



NOTE 1: 1/4" LONG STAINLESS 304
 PLUG 0.001" - PRESS IN
 AND WELD

DUMMY PROBE TUBE

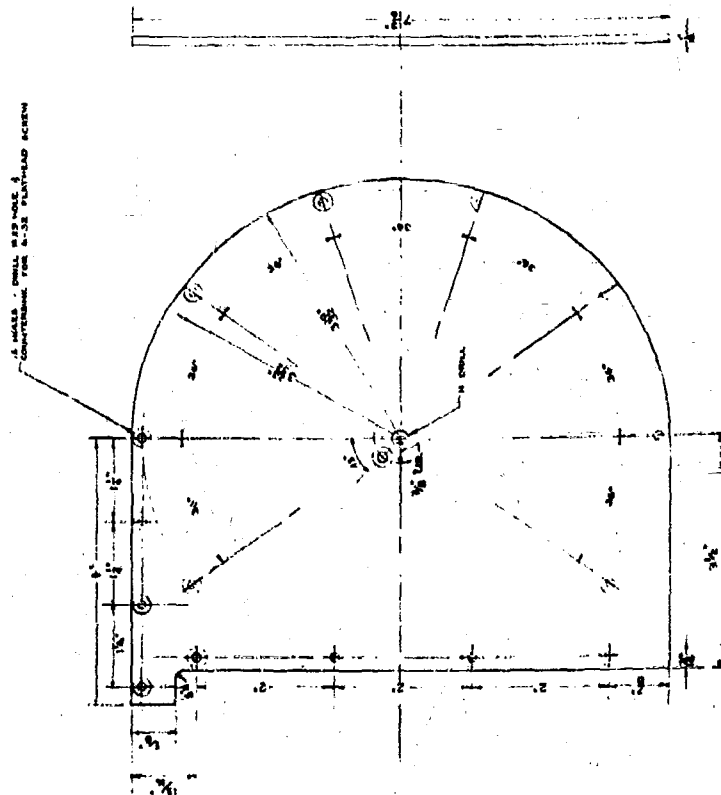


STRIP MUST BE FITTED TO GROOVE ON
DWG 429-108 AND SEALED IN PLACE
WITH GASKET CEMENT (PART #5)

STRIP FOR SEALING PRESSURE RELEASE GROOVE
MATERIAL: 24 ST DURAL BLACK ANODIZED FINISH



STOCK : 24 ST.
WARRANTY: FACTORY 1 YR.
NORMALLY 2 YEARS
LACK MAINTENANCE TIPS



TERMINATION COVER PLATE
 STOCK: 24-57 (1/8" stock)
 Part Number: 1000

